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Development of a Single-phase High Frequency UPS with Backup PEM Fuel Cell and Battery

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***Abstract*-This paper presents a 300 W single-phase high frequency uninterrupted power supply (UPS) with backup proton exchange membrane fuel cell (PEMFC) and battery, DC/AC inverter, DC/DC converter, AC/DC rectifier, and AC/DC recharger. The principle and structure of the PEMFC/battery hybrid UPS system are introduced and discussed. Key practical techniques of the design are presented, including the design of the PEMFC generating system, the control technique of the AC/DC rectifier, AC/DC recharger, DC/AC inverter and DC/DC converter based on a microcomputer MC68HC11K4 and other integrated circuit chips. Experimental results show that during the switching process from battery to PEMFC, and vice versa, the UPS can provide an uninterrupted alternate voltage for the load, with low cost, low weight, small volume and size, great reliability and maintainability.**

Keywords-High frequency uninterrupted power supply (UPS), proton exchange membrane fuel cell (PEMFC), PEMFC/battery backup UPS system.

I. INTRODUCTION

With the development of information technology, uninterruptible power supply (UPS) systems have become very popular together with the instruments of computers, medical/life support systems, telecommunication and industrial controls. When the utility grid power has a dropout, the computer power supply can degrade and the computer may crash. If the input AC source has sags and surges, the computer may produce error message. To maintain a high quality power to the loads such as computers and communication equipments, UPS is unavoidable. A high performance UPS system should have a clean output voltage with low total harmonic distortion (THD) for both linear and nonlinear loads, high efficiency, great reliability and fast transient response for sudden power grid failure and load changes [1]. Therefore, UPS systems that can keep the information and data from being destroyed are desired. Particularly, with the popularization of personal computers and Internet, low capacity UPS products will take an increscent part in the industrial and domestic markets. Due to the highly competitive world market, many technical advances, such as higher power density, higher efficiency and intellectualized control are implemented into the UPS system. In summary, an ideal UPS should have the following features: regulated sinusoidal output voltage with low THD and independent from the changes in the input voltage or in the load, on-line operation that means zero switching time from normal mode to back-up mode and vice versa, low THD sinusoidal input current and unity power factor, high reliability, high efficiency, low electromagnetic interference (EMI) and acoustic noise, electric isolation, low maintenance, and low cost, weight, and size.

Due to high electrical efficiency, flexibility with respect to power and capacity, long lifetime and no pollutions, fuel cells are rapidly becoming a significant source of power in our society, and their use in a variety of applications is inevitable [2]. One direction of application is the use of a fuel cell as the power source in a UPS. The primary purpose of using a fuel cell instead of a battery as the power source is due to the fuel cell's high energy density, and hence the ability to operate a UPS system for a very long period of time during a utility grid failure. However, when the fuel cell starts up, it may take several seconds to reach the rated output voltage. Therefore, rechargeable batteries or ultra-capacitors are still needed in an UPS system.

Among fuel cell technologies, the liquid-fed direct methanol fuel cell (DMFC) and the proton exchange membrane fuel cell (PEMFC) based on hydrogen fuel cells are the most promising [3, 4]. In the UPS system with backup PEMFC and battery hybrid power sources, the previous study is that the PEMFC could only be considered and used in the UPS system. But when AC line, i.e. utility grid power source is interrupted, and the hydrogen will be supplied to the PEMFC stack, the UPS system should ensure that there is enough fuel and battery capacity for providing the power needed by the external load. When the external load shows, however, a sudden change, or the PEMFC starts, the hydrogen cannot be fed fast enough to the PEMFC stack. To provide the supply of enough power to the external load, the UPS system keeps adopting the lead-acid battery for protecting the PEMFC in order to prevent excessive use of the PEMFC and to feed power smoothly to the external load. Therefore, an UPS system with a PEMFC/battery hybrid power source in parallel is made.

In this paper, a single-phase high frequency 300 W UPS with a PEMFC/battery hybrid power source is developed. Fig. 1 illustrates schematically the structure of the UPS with a backup 300 W PEMFC generating system and battery, which consists of DC/AC inverter, DC/DC converter, AC/DC rectifier, and AC/DC recharger, and their data-acquisition and control units. The UPS supplies the linear and nonlinear loads with the required uninterruptible AC power. The PEMFC stack operates on hydrogen and air. Because of the slow start-up of the PEMFC stack, which may take a few seconds, the small capacity battery is required for UPS applications. The UPS system designed has a lot of advantages, such as low cost, weight, size and so on.

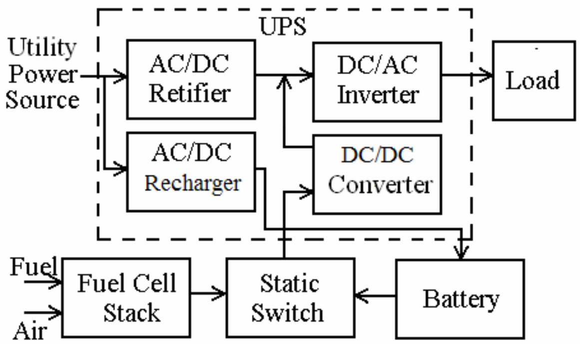


Fig. 1. Single-phase high frequency UPS with backup PEMFC and battery

II. Design of UPS System

A. Design of AC/DC Rectifier

By adopting the design concepts of the mature technology, a boost active power factor corrector (APFC) with universal input and fixed output voltage is applied and then designed based on a high power factor pre-regulator UC3854. It has been applied in high frequency UPS products designed by the Fuel Cell Laboratory at the University of Technology, Sydney (UTS). Fig. 2 shows the single-phase uninterrupted APFC AC/DC rectifier and its working pattern.

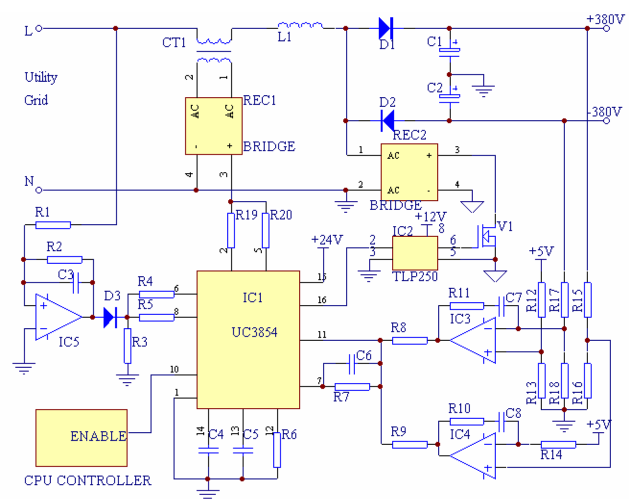


Fig. 2. Single-phase uninterrupted APFC AC/DC rectifier

Under the normal state of utility grid power source (160~265 V), the APFC AC/DC rectifier converts the AC voltage into DC voltages of ±380 V. Based on the high power factor pre-regulator UC3854 with a working frequency of 20 KHz, through the action of the MOSFET V1, the APFC AC/DC rectifier can modify the input current of the UPS into a sine wave, control the power factor of boost PWM to 0.99, and limit the THD less than 5%.

B. Design of DC/AC Inverter

Using CPU controller consisting mainly of microcomputer MC68HC11K4, a DC/AC inverter has been designed to supply the loads with a pure sine wave voltage. The DC/AC inverter, the core of a UPS, usually operates with a sine PWM (SPWM) strategy under feedback control to achieve these specifications. A high performance feedback control scheme such as a PID control loop has been proposed for the optimal control of the UPS system. The PID feedback loop control strategy has fast transient response but high THD for nonlinear loads. Fig. 3 shows the schematic circuit model of the designed DC/AC inverter. The working frequency of the inverter is 15.6 KHz.

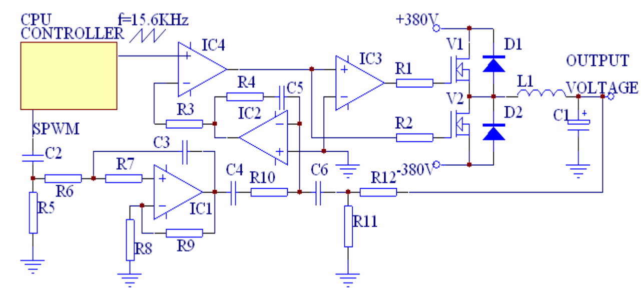


Fig. 3. Circuit schematic model of DC/AC inverter

C. Design of AC/DC Recharger

A basic switch power system with universal input and adjustable output voltage is designed based on a high performance current mode PWM controller UC3845. Fig. 4 shows the circuit model of the AC/DC recharger. Its working frequency is 20 KHz.

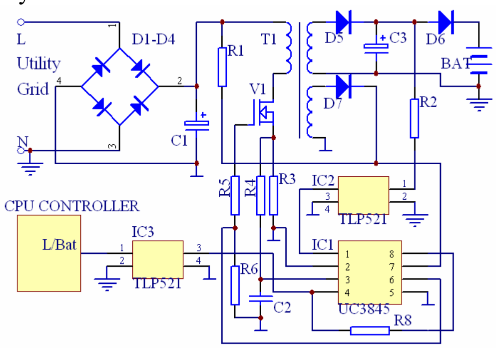


Fig. 4. Circuit schematic model of AC/DC recharger

D. Design of DC/DC Converter

A general and practical DC/DC converter for single-phase high frequency UPS is designed based on a regulating pulse width modulator UC3525. The PEMFC and battery are two kinds of low-voltage and high-current power source, so their rated output voltage (36 VDC) should be boosted up to about ±380 VDC before the UPS inverter converts them into a 220 V, 50 Hz AC source. This boosting action is performed by DC-DC converters. Moreover, in the UPS system, energy storage units, such as battery and super-capacitor, are required in order to power the auxiliary units in the starting-up stage of PEMFC generator or during a sudden change of external load. Fig. 5 illustrates the schematic circuit model of the DC/DC converter. The working frequency of UC3525 is 20 KHz.

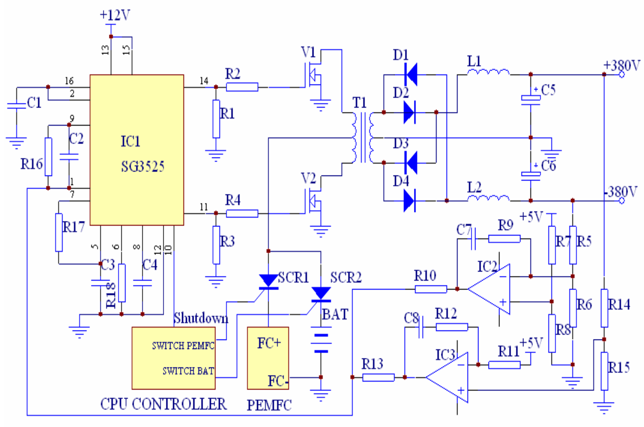


Fig. 5. Schematic circuit model of DC/DC converter

III. Structure of PEMFC Generating System

The PEMFC generating system, as shown in Fig. 6 [5-7], consists of a PEMFC stack, water-cooling components, air-cooling, H_2 humidifying and filtering, and temperature and pressure monitoring. Three types of gases, hydrogen, nitrogen and air/oxygen, are used in the system. The control software based on LabVIEW is designed and used to control the whole process of the PEMFC generating system and measure the operation parameters, such as the work temperature, voltage and current, pressure, input and output mass flows, humidity of the hydrogen and air/oxygen, the voltage and current of the battery and so on.

The solenoids, pressure and temperature transmitters, mass flow controllers and other components are also shown in the figure, providing a good reference for future researches.

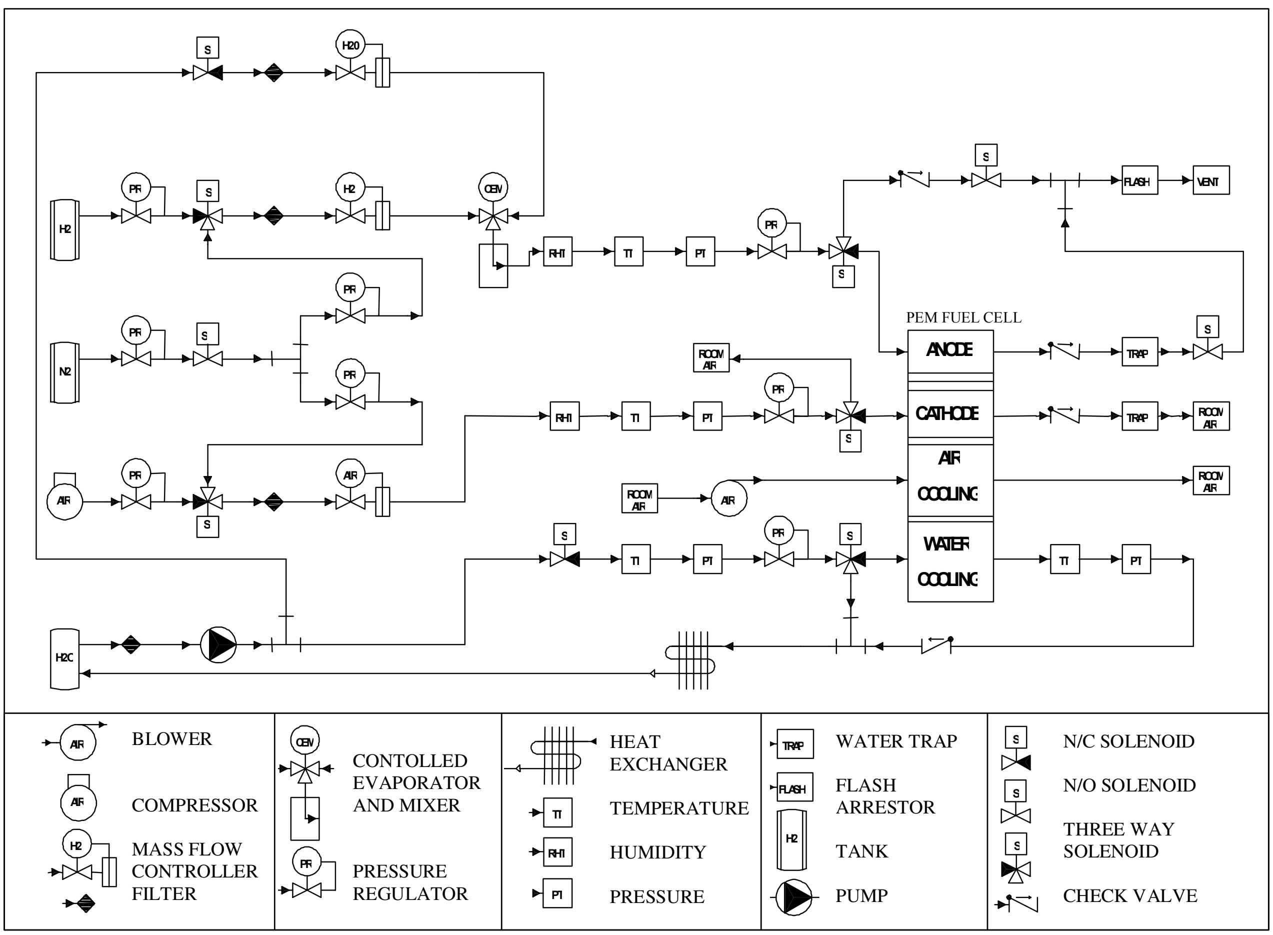


Fig. 6. Schematic diagram of PEMFC generating system

IV. Experiment Setup and Results

A. Experimental Setup

The experimental set-up consists of a UPS system, PEMFC generating and test system, lead-acid batteries and a data-acquisition system, which are multifunction I/O devices NI6036E, analog voltage output devices NI6713, parallel digital I/O interface PCI-6503 and analog multiplexer with temperature sensor AMUX-64T. The UPS system with backup PEMFC and battery provides the AC power source and controls the linear loads (e.g. lamp box) and nonlinear loads (i.e. PC), while the data-acquisition system measures and records the required information. In the PEMFC generating and test system, both hydrogen and air are regulated by mass flow controllers (type: F-201C-GAS-22V and F-112AC-GAS-22V, Bronkhorst). Concerning the application of the PEMFC system in UPS system, the option to humidify the hydrogen is not used. The temperature and humidity of air and hydrogen can be measured at inlet by the hydrotransmitter (type: HD2008TV1, Delta OHM) as well as the pressure transmitter (type: AUS EX 1354X, Burkert) between the inlets of cathode and anode. The output of the UPS is connected to a lamp load that is used in a constant voltage mode. All physical parameters such as currents and voltages of the UPS, PEMFC stack and battery, gas mass flow of the reactants, pressure drop in the flow fields, relative humidity and temperatures of air and hydrogen are recorded with the data-acquisition system. Fig. 7 shows a photograph of the experiment environment.

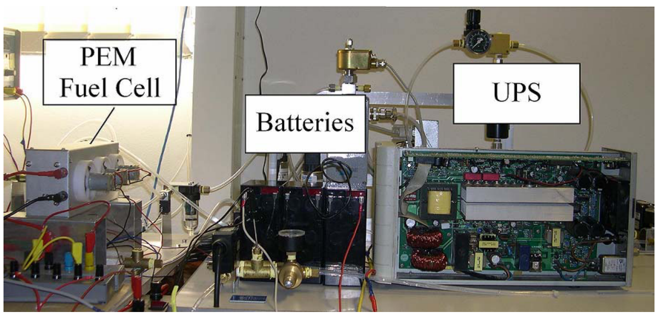
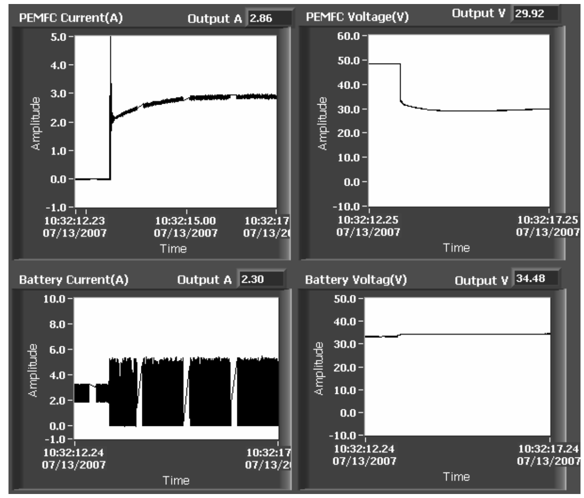


Fig. 7. Photograph of the experiment environment

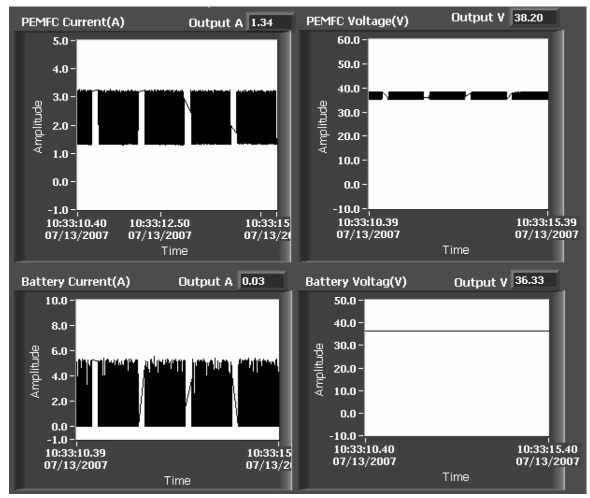
B. Experimental Results

Experimental study has been conducted on the designed UPS with backup PEMFC and battery. In the case of utility grid power failure in the system of Fig. 1, the UPS system supplies the load with the required AC power. During the period of power failure, firstly the battery supplies UPS, and then the backup PEMFC generating system begins to warm up. When its voltage goes up to a predetermined value, a signal is given to the CPU controller to make the static switch be connected to the PEMFC generating system. Therefore, the load of the UPS can be fed by a suitable AC power from the PEMFC power source.

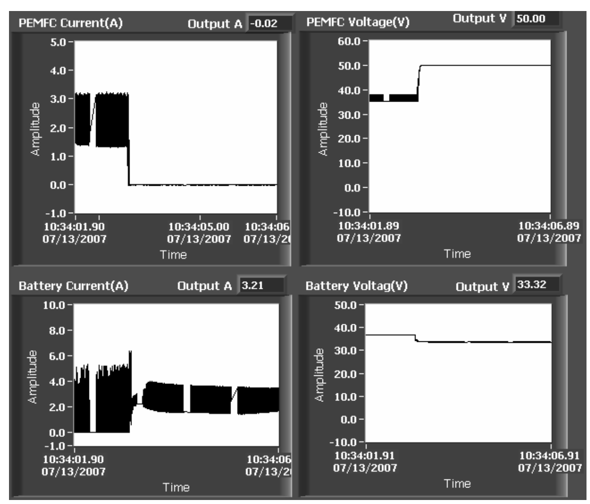
The experimental results reveal that after the PEMFC stack starts up and works in the normal state, the UPS system will be switched from battery power source to the PEMFC power source, and the UPS can be used to provide an uninterrupted alternate voltage. In other words, when the PEMFC supplies the UPS, its voltage will decrease and it current will increase, as shown in Fig. 8(a). Fig. 8(b) illustrates the normal operation state when supplying UPS with PEMFC power source. Once the PEMFC generating system has a failure, or the load of the UPS suddenly changes, the UPS system will automatically be switched to the battery power source, as shown in Fig. 8(c), and the response time of the switch is zero. After the PEMFC generating system adjusts the hydrogen mass flow or air mass flow and make its voltage go up to the rated value, the UPS system is switched from battery power source to the PEMFC power source, as shown in Fig. 8(a).



(a)



(b)



(c)

Fig. 8. Experimental results of output voltage and current of the PEMFC stack and battery when: (a) switching from battery to PEMFC, (b) steady operation with PEMFC power source, and (c) switching from PEMFC to battery.

V. CONCLUSION

The development of a single-phase high frequency UPS system with backup PEMFC and battery hybrid power source for backup and emergency power applications is presented. The prominent features of this UPS system includes 32-cell self-humidifying PEMFC stack, 3-cell lead-acid battery, high power factor AC/DC rectifier, high efficiency DC/DC converter, CPU controlled DC/AC inverter, simple AC/DC recharger, and data acquisition and control unit. Schematic circuit models and experimental measurements are employed to investigate the advantages of mature design technology, relatively simple circuits and integrated chips, resulting in high reliability, high efficiency, low EMI and acoustic noise, low maintenance, and low cost, weight and size. The PEMFC generating system is connected electrically with the battery, and the switching operation between the PEMFC and battery has been tested. The experimental results show that the developed PEMFC systems can be successfully used for backup and emergency power applications.

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