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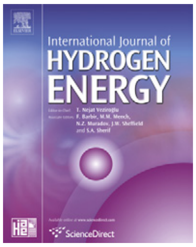

Distributed generation system with PEM fuel cell for electrical power quality improvement

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ABSTRACT

In this paper, a physical model for a distributed generation (DG) system with power quality improvement capability is presented. The generating system consists of a 5 kW PEM fuel cell, a natural gas reformer, hydrogen storage bottles and a bank of ultra-capacitors. Additional power quality functions are implemented with a vector-controlled electronic converter for regulating the injected power.

The capabilities of the system were experimentally tested on a scaled electrical network. It is composed of different lines, built with linear inductances and resistances, and taking into account both linear and non-linear loads.

The ability to improve power quality was tested by means of different voltage and frequency perturbations produced on the physical model electrical network.

1. Introduction

Nowadays, the traditional centralized generation is slowly changing to a new paradigm, driven by environmental considerations and by the flexibility of the topology. This new model, usually known as distributed or embedded generation, is characterized by the small generation size, the proximity to the loads, and its connection to distribution networks. Usually, the generating equipment is renewable, or at least features clean and efficient energy systems.

The main purpose of this equipment is to generate the active power required by the loads. Besides, the flexibility of the generating systems allows their utilization as both voltage regulation devices, and as elements for power quality enhancement. The proper distribution of the different technologies in the network also reduces losses and increases the reliability and efficiency of the electric system.

In addition to traditional generating equipment, like diesel or gas engines, new technologies have appeared, like micro turbines or fuel cells (FCs) [1]. With these systems, low power generation can reach a high efficiency. FCs appear as one of the most promising due to their good efficiency even at partial load, and especially due to their clean electric generation, with only water and heat as by-products. Also, their low noise and static operation allow them to be used even in domestic generation [2].

Among all the different types of FC, the Proton Exchange Membrane Fuel Cells (PEMFCs) are one of the main choices for the range of powers used in distributed generation (DG). An interesting characteristic of this type of FC is its low operating temperature (less than 100 °C), which allows the system to be brought on-line rapidly and to install it close to the consumer.

In this paper, a DG system with power quality improvement functions is presented. It is based on a PEMFC with

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a rated power of 5 kW. Its network behavior was evaluated on a scale model of an electrical grid constructed for this purpose. In addition to delivering active power to the grid, the system is designed to mitigate the following perturbations: voltage sags, voltage swells, voltage fluctuations, voltage collapse and frequency variations.

The paper is structured as follows: first, a general description of the system is presented. The control algorithm is then explained, followed by a description of the main characteristics of the scale electrical grid. The paper concludes with the results of the perturbation compensation.

2. System description

Fuel cell systems, like any DC generating system, need an electronic converter to interface with the AC system. In DG applications, the converter is connected in parallel with the network, in the same way a traditional generator is connected. Compensation systems, on the other hand, can be connected using either a series or shunt topology.

The system in question was connected in parallel to the grid to allow it to inject active power as a DG system, while simultaneously acting as a compensating system.

Fig. 1 shows the schematic diagram of the experimental set-up. The system is divided into 10 modules.

(a) The first module (M1 in Fig 1) is a PEMFC generating system, Fig. 2 a, with a rated power of 5 kW. The hydrogen is obtained from an in-line natural gas reformer, which is fed from the laboratory natural gas line. The high temperature of the reformer imposes a long start-up time (1.5 h from cold state to full hydrogen production). In order to supply hydrogen during this time, an external storage system is used which is refilled by the reformer once on line. The output from the stack, with a voltage between 37 and 75 VDC, is stabilized in the module to provide a 36 VDC output. The reformer is the slowest component in the set-up, dominating the transient response of the whole system.

(b) The ultra-capacitor (UC) bank, module (M2), Fig. 2b, serves two purposes. The first one is to store enough energy to supply the loads while the PEMFC stack is starting; the second one, is to improve the system dynamics, providing a faster response than the stack itself. The energy stored in the UC bank is approximately 0.5 kWh (at 80 VDC) and 0.25 kWh, yielding initial and final voltages of 65 and 36 VDC (the actual range of the system in the initial state). It consists of seven parallel branches of five UCs in series, with an overall capacitance of 430 F. The maximum voltage of each UC is 16 VDC, for a maximum series voltage of 80 VDC.

The bank is connected to the 36 VDC bus by a four-quadrant DC–DC converter, which controls the charge and discharge of the UC bank.

(c) To interface the 36 VDC bus with the electrical network, a DC–DC boost converter (M3) and a three-phase Voltage Source Converter (VSC) (M4) are used. In this configuration, the VSC operates with low voltages and high currents. This is a widely used option in the most common distributed generation systems with energy generation based on fuel cells, small wind turbines, solar photovoltaic, microturbines, etc., [3].

(d) The output of the VSC is connected to the grid through an inductive filter (M5) that smoothes the output current generated by the converter.

(e) The connection to the 400 VAC network is made through a 230/400 V Yy0 transformer (M6). In this way, the converter is able to generate up to 400 VAC to supply a 230-VAC bus, thus boosting its ability to inject power into the grid.

(f) A scale electrical network (M7) comprising several lines was built to represent an actual electrical network.

(g) The control system (M8) for the VSC (M4) regulates the characteristics of the power injected to the network by means of a vector control scheme and a spatial vector modulation algorithm. It also detects perturbations in the system. The control algorithms were implemented using a Digital Signal Processor (DSP).

(h) Critical loads (M9) are those considered as 'quality' loads. Usually they are supplied by the grid through the scaled

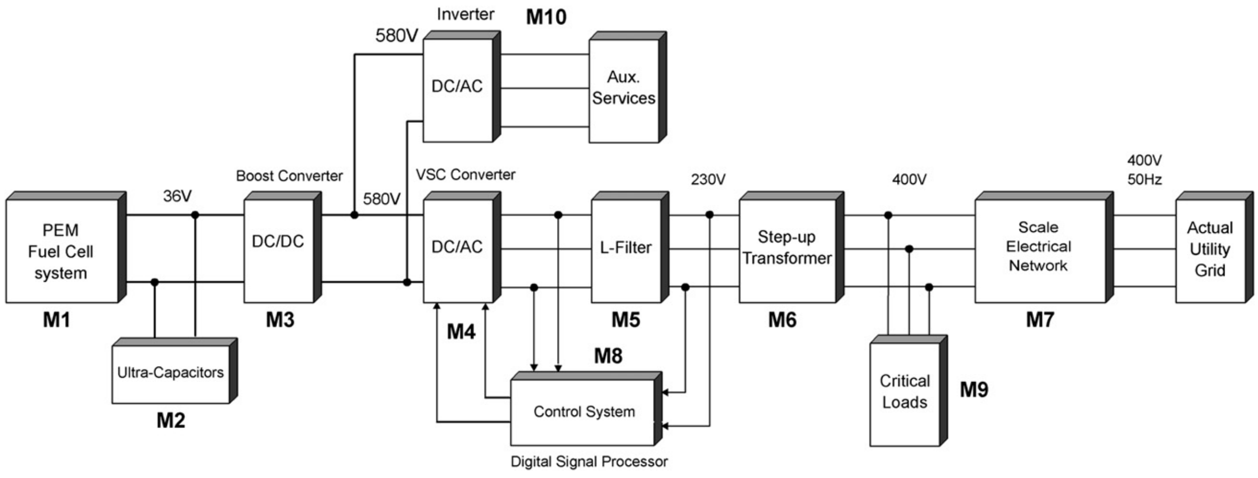

Fig. 1 – Block diagram.