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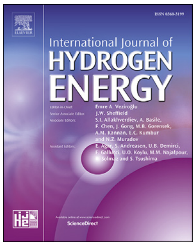

Power management in fuel cell based hybrid systems

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ABSTRACT

This paper presents modeling, design and analysis of a Grid-connected Hybrid Photovoltaic Fuel Cell System (HPVFCS) with a reactive power compensation feature. A hydrogen based fuel cell is a proven technology and its use along with the photovoltaic system (PV) can lead to energy stability in grid-connected or standalone systems. In this paper, the Voltage Source Converter (VSC) is connected between the DC output of HPVFCS and an AC grid. The control strategy employed guarantees the maximum utilization of the PV array and the optimum use of an FC. The active and reactive power of VSC can be controlled independently using P-Q control theory. The additional function of the reactive power compensation using P-Q control theory can enhance the performance of the distribution systems where HPVFCS system is connected. Its applicability is verified by the test bench created with MATLAB/Simulink®

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Introduction

The demand for energy is increasing rapidly with increasing population and industrialization. Till recent years, the centralized power generation was a preferred choice due to the fact that the transmission of generated power is easier than transportation of the fuel. However, for loads, which are quite far from these stations, suffer from the drawbacks reminiscent of; (1) significant T&D losses (2) poor voltage regulation & low power quality and (3) low reliability. Further, the electricity is generated typically from the conventional sources like fossil fuels and nuclear power, having several negative environmental footprints resembling pollution, hazardous chemical waste, and climatic changes.

The shortfalls mentioned above can be handled by generating the power “locally” from the sources like photovoltaic (PV) arrays, fuel cell (FC) stacks [1,2], wind energy, small hydro, etc. The concept of generating power locally is well known as distributed generation (DG) and its advantages include low distribution losses, better power quality, and high reliability. Among many renewable sources, solar PV power generation is well accepted due to its pollution free clean energy as well as the steady decline in the cost of PV devices and systems. However, an output power of PV plant is directly proportional to solar irradiance which is intermittent and stochastic in nature due to real-time meteorological conditions. Today's electric grid, on the other hand, relies on highly trustworthy power generating stations (coal, hydro, gas, nuclear) and can address different load dynamics along with strict deterministic scheduling approach. However, if a PV source can be coupled with a suitable auxiliary energy source, the drawbacks of the conventional power generating systems can be mitigated. The energy stockpiling devices such as hydraulic pumps,

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supercapacitors, flywheels, electrochemical batteries etc. with sufficient dynamic responses are discussed in Refs. [3,4], but in general, these systems have low storage capacity and they accumulate energy in the range of seconds or minutes. In this paper, HPVFCS is proposed that can help to stabilize the unregulated PV energy generation. In the proposed system, the FC is used to produce deficit electrical power when the load demand exceeds the power produced by PV. An FC is eco-friendly, has higher energy density, and can generate power as long as the fuel is supplied. FC incurs running cost (Hydrogen Fuel) but due to higher conversion efficiency, their performance is better compared to the diesel generator [5].

Hybrid system with the use of PV and FC sources is proposed in Refs. [6,7] in which PV and FC sources are connected to a utility through two VSCs (two power inverters). A better system is shown in Refs. [2,4], which overcomes the drawbacks of the earlier ones [6,7]. Paralleling of inverters' outputs is replaced by paralleling of dc–dc converter's outputs have advantages of (i) stable dc bus voltage and (ii) controllable power devices reducing from 12 to 8, and hence, switching losses are minimized.

But, the integration issues associated with the development of a grid-connected hybrid system using the FC as the backup system are not well understood or documented in the literature. Furthermore, and perhaps, more importantly, the dynamic interactions between system components of such system (HPVFCS) that occur while servicing real-world loads (distribution system) remain unexplored. Hence, in this paper, a brief description of the challenges related to grid connected HPVFCS, and its dynamic behavior has been carried out. The system proposed here is for the support of critical loads located in remote places where the grid is in pitiable condition. Looking towards the future of power system it is expected by 2025, that such system will be technically and economically viable for future smart and pollution free cities.

The HPVFC system is connected to the grid by a VSC. The present VSCs are complying with IEEE 1547 and do not take part in any other grid support activities [9,10]. However, the future VSCs of higher power levels can perform several grid support functions including Spinning Reserve, Peak shaving technology [12] and reactive power support [1–3,11]. Thus, integration, control and optimal operation of HPVFCS units have become the main area of research in the design and operation of power distribution systems. Grid-connected, such Hybrid system (here HPVFCS) covers a wide range of power levels, ranging from small, single-phase residential rooftop systems to large three-phase, multi-megawatt systems using PV and also wind systems [13]. The work carried out in this paper is for medium scale system and can be extended to large systems also.

Numerous industries in the developed countries use active power factor compensation techniques to match the power factor regulations. Similarly, some specialized applications require superior power quality that has prompted the use of active filters. In these cases, the high cost of active systems can partly be paid by connecting HPVFCS system on the dc side. On the other hand, the grid connected HPVFCS can provide an additional function of Power Factor correction, UPS and/or Active Filter [14,15]. The applied control strategy in this paper has the advantage that the HPVFCS system will work for the whole day. These ancillary services can be provided by grid requirements and codes [16].

Intermittent and fluctuating nature of the power output and its solution by using fuel cell is shown in Ref. [17]. The performance enhancement of the proton exchange membrane fuel cell is considered in Ref. [18]. A complete review of the proton exchange membranes for fuel cell applications is shown in Ref. [19] wherein a focus is made on considerable application-driven interest in lowering the membrane cost and extending the operating window of PEMs. Whereas [20], has shown an energy management strategy to optimize the fuel cell consumption in a hybrid vehicle, which again is in line with the presented research work.

HPVFC – system description

In the HPVFC systems, PV is used as a primary energy source and FC stack as a backup energy source. Both systems are connected in parallel to a common dc bus through two individual dc–dc boost converters as shown in Fig. 1. The outputs from both the power sources are integrated on the dc side, and the inverter provides desired power to the network and the grid connected load.

The proposed hybrid system consists of the following:

A.50 kW photovoltaic array
B. 30 kW SOFC (Solid Oxide Fuel Cell)
C. 60 kVA VSC
D. 30 kW, 20 kVAR Load

Control strategy

To operate the proposed HPVFCS, following are the challenges to be met.

1. The system should transfer energy from dc link to the three-phase AC system with controlled active and reactive power, without injecting harmonic currents.
2. The Dedicated control circuit is to be developed that ensures a proper load sharing between the two converters [21,22].
3. A stiff dc input voltage to the inverter is necessary at all modes (i) even though PV output is changed or (ii) SOFC start/stop supplying power.
4. The control strategy employed must take care of the different time constants of PV and FC systems.
5. Dynamics of the Paralleled DC–DC Converters: (detailed mathematical analysis is carried out in Ref. [23], hence, not discussed here).

The whole control strategy is divided into two groups.

A. Control of DC–DC Converters
B. Control of VSC Converters

Control of DC–DC converters

This control is further classified as;

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