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MICROGRID-BASED CRYOGENIC ENERGY STORAGE AS A PART OF INTELLIGENT ENERGY INFRASTRUCTURE MANAGEMENT (IEIM)

Abstract: Integration of advanced electrical machines with electrical power systems and renewable energy is at the heart of the dedicated Liquid Hydrogen Laboratory (LHL) at the University of Cambridge. Generation, storage and use of the hydrogen in conjunction with a patented dynamic energy storage system are an integral part of the proposed combined heat and power (CHP) IEIM Project. The aim of the project is to address intelligent energy infrastructure management IEIM of a smart micro grid, which combines hydrogen and electricity. To build a powerful relational database for the entire physical infrastructure based on combined heat and power elements, a sub-system needs to be established to monitor the status of interconnectivity to the grid. This information will be mapped onto the database to provide a real-time view of the energy network's physical interconnectivity with the grid, significantly reducing the environmental impact of the total electricity supply system. Considering the nature of the heat and power elements fibre optic based sensing techniques will remotely monitor the patching fields and provide an accurate map of the connectivity and constantly monitor changes in real-time.

1. Introduction

Until multisource renewable energy can provide widespread sustainable power delivery, alternative energy storage devices have to be considered. A future hydrogen economy considers transfer [1] and storage of hydrogen in many forms such as in metal hydrates, compressed gas, and also as a liquid. Hydrogen in its liquid form at 20K has a very important cryogenic property allowing it to be a coolant for superconducting energy devices such as those used in high energy physics and energy magnets [2-4], and also energy storage devices like superconducting flywheels [5]. The applications of medium temperature superconductors like MgB_2, and high temperature superconductors like $YBa_2Cu_3O_7$, can benefit from the low cost of cooling by liquid H_2 at 20K. Our work on SOFCs and SOECs in the framework of international and national projects and also long-term expertise in hydrogen cryoscience, enable us to present the concept of a sustainable liquid hydrogen cycle in conjunction with energy generation, storage and usage.

2. Hydrogen Lab

The research activities to take place at the Liquid Hydrogen Laboratory at Cambridge University, include: plasma assisted hydrogen and carbon generation from CH_4, hydrogen compression (solid-state technique and using a new compressor), hydrogen liquefaction (Linde process combined with re-liquefaction by magnetocaloric effect), LH_2 storage, an indirect hydrogen cooling system using a closed cycle helium cryofan, DC transmission superconducting cables, FCLs (Fault current limiters), hybrid SOFCs/SOECs, carbon utilization in DCFCs, fibre optic temperature monitoring and H_2 concentration systems.

The main purpose of the project is to provide combined heat and power (CHP) along with IEIM of the microgrid based on the hydrogen generation, storage and use for a decentralized economy. The individual subsections of the system will be discussed and described in the next chapters.

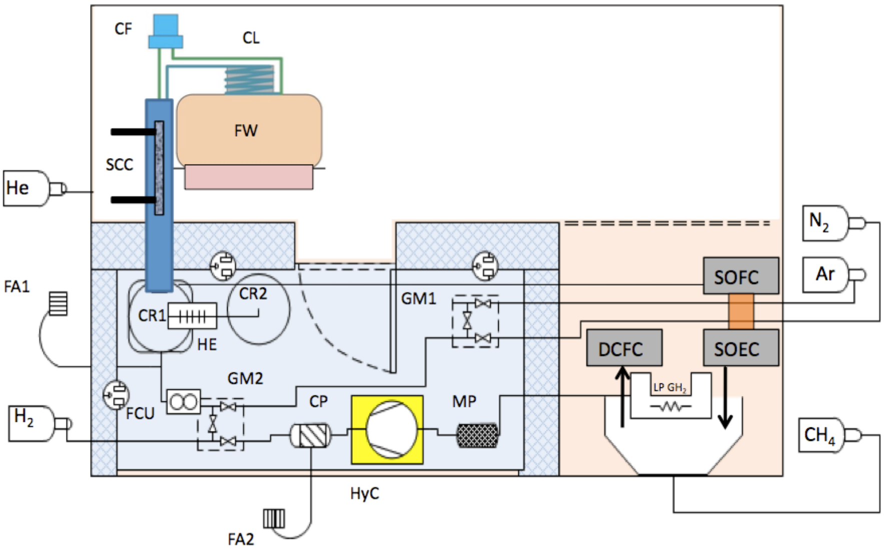

Fig. 1. Overall arrangement of the hydrogen Laboratory at MSM, University of Cambridge, where generation, liquefaction, storage and use will be performed. CR1–LH_2 liquefier; CR2 –LN_2 liquefier or LN_2 dewar; CF-cryo-fan (He); CL–cryo-loop (He). CP–cryo-purification; DCFC – direct carbon fuel cell; FA–flame arrester; FCU–flow control unit; FW–superconducting flywheel; GM–gas manifold; HE–heat exchanger; HyC–Hydrogen compressor; LNGH_2–low pressure microwave plasma H_2 production unit; MP–membrane purification; SCC – superconducting DC cable (demonstrational); SOFC–Solid oxide fuel cell; SOEC- Solid oxide electrolyte cell.

2.1. Smart microgrid structure

Liquid hydrogen has two main purposes: an energy carrier and a cryogenic liquid [6-8]. Concerning the energy carrier purpose it is envisaged that hydrogen can be used to balance varying renewable energy supply with varying demand in a decentralised energy infrastructure as presented schematically in Fig 2. The proposed IEIM integrates DC/AC network with LH_2 infrastructure and energy storage FL system. It has been planned that the renewable energy solar thermal will be used to generate directly electricity for the LHL, see Fig. 3. As presented in Figure 1 and 3, the superconducting flywheel in combination with the hydrogen storage form an energy reservoir to meet the peaks in energy demand.

The aspect of decentralised energy storage can be seen as a caloric value of the liquid hydrogen itself (100%wt H_2), with potential for an additional physical cryosorption of hydrogen (7wt% H_2) and also as an efficient coolant for superconducting energy storage devices such as a flywheel with rating 10kWh. Calculations for the cooling efficiency of the large electromagnetic non-superconducting pulse coil, supported by testing results of the purpose a build installation in USA conducted for LHe, LH_2 and LN_2 show very clearly that cooling directly by helium or neon is 70 times and 100 times more expensive than indirect cooling by LH_2 [4]. Taking into account the prices of 1l of LH_2 ~ £0.5, LHe ~ £3) and Ne ~ £150 and also the fact that hydrogen is the only element that is an energy carrier, the choice of LH_2 as a cryogenic cooling medium for cryomagnetic applications is rather apparent.

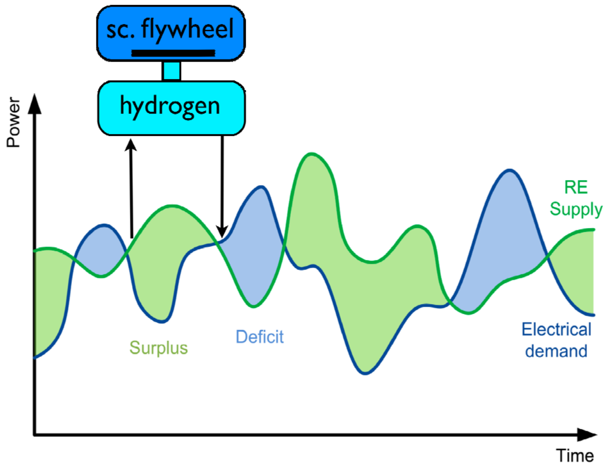

Fig. 2. Schematic of the way to balance varying renewable supply with varying demand using liquid hydrogen and superconducting flywheel technology.

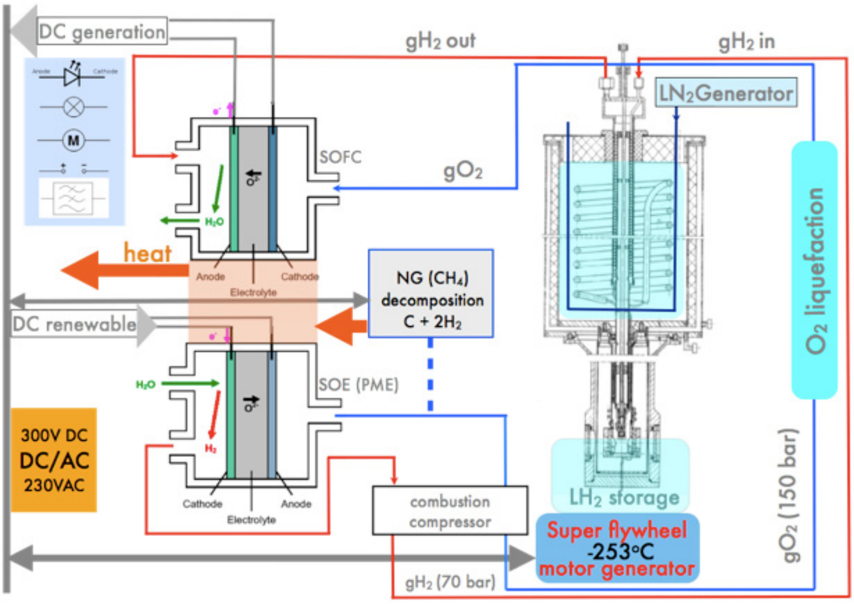

Fig. 3. Schematic of the CHP hydrogen cycle at the LHL at Cambridge University [8].

2.2. H_2 Liquefaction system

The energy requirement for conventional large-scale hydrogen liquefaction is estimated to be as high as 30% of the calorific value of the generated LH_2. New approaches that can lower the energy requirement and thus the cost of liquefaction, especially at low hydrogen production rates, need to be developed for a decentralised hydrogen economy [8].

We propose a development of a tandem cooling system, presented in Fig. 4, where high temperature electrolysis (SOEC) at elevated pressure provides compressed O_2 and H_2 needed to liquefy H_2. Oxygen has an inversion temperature of 764 K and can therefore be effectively cooled by the combination of Joule - Thomson valve and turbine based expanders. In our design lowered temperature liquid oxygen (super-cooled O_2) plays an important role in increasing hydrogen liquefaction efficiency. To improve safety during liquefaction of hydrogen, a novel composite solid nitrogen reservoir will be researched as a heat exchanger between liquid O_2 and gH_2. Cryogenic LH_2 is going to be stored in a cryogenic super-insulated Dewar integrated with a liquefier as presented in Fig. 1 and Fig 3. Additionally a thermal link from the LH_2 energy storage to the superconducting flywheel is a viable option.

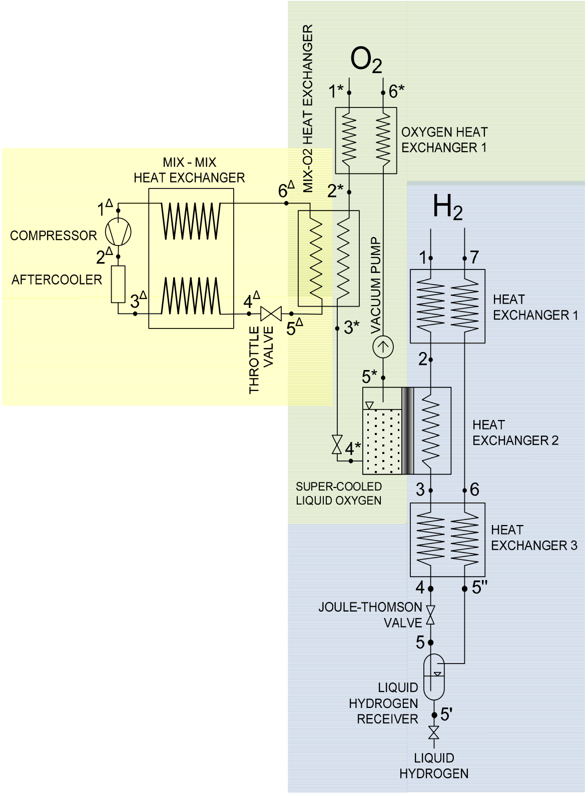

Fig. 4. Hybrid O_2/H_2 liquefier: Schematic of the novel design of a oxygen and hydrogen cycle characterised by 40% liquefaction capacity of hydrogen at rate of 1ml of LH_2/min. The O_2/H_2 liquefier is combined at the initial cooling stage with a developed PEN J-T cycle marked in yellow [6].

Compared to conventional and existing liquefaction systems using a Joule-Thomson (J-T) valve, magnetic refrigeration for hydrogen liquefaction has great potential. One of the greatest advantages of magnetic refrigeration is that its cooling cycle can closely follow the Carnot cycle [9]. Therefore an additional consideration is given to the Magneto-caloric effect, which is going to be employed to re-liquefy the LH_2 after the J-T expansion valve with a Carnot efficiency of more than 50%.

3. Integration of electrical machines with the Power System

Presented in Fig. 2 and Fig. 3 proposed integration of the hydrogen cooled superconducting flywheel energy storage and also hydrogen fuel source with the electricity grid, underlines role of microgrid-based cryogenic energy storage as a part of intelligent energy management infrastructure.

4. Bibliography

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