INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 38 (2013) 14638–14653

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journal homepage: www.elsevier.com/locate/he

Integration of large-scale hydrogen storages in a low-carbon electricity generation system

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ARTICLE INFO

Article history:
Received 5 July 2013
Accepted 27 August 2013
Available online 7 October 2013

Keywords:
Low-carbon electricity
Hydrogen energy storage
Coal gasification plant
Combined cycle gas turbine
Molten carbonate fuel cell
Wind power

ABSTRACT

This study investigates the overall feasibility of large energy storages with hydrogen as energy carrier onsite with a pre-combustion carbon capture and storage coal gasification plant and assesses the general impacts of such a backup installation on an electricity generation system with high wind power portion. The developed system plant configuration consists of four main units namely the gasification unit, main power unit, backup power unit including hydrogen storage and ancillary power unit. Findings show that integrating a backup storage in solid or gaseous hydrogen storage configuration allows to store excessive energy under high renewable power output or low demand and to make use of the stored energy to compensate low renewable output or high power demand. The study concludes that the developed system configuration reaches much higher load factors and efficiency levels than a plant configuration without backup storage, which simply increases its power unit capacity to meet the electricity demand. Also from an economical point of view, the suggested system configurations are capable to achieve lower electricity generation costs.

1. Introduction

The integration of adequate energy storages in electricity production systems can help to reduce grid requirements and to smooth varying renewable power inputs. A promising near- and long-term strategy may be the combination of 'clean' fossil fuel usage by Carbon Capture and Storage (CCS) systems and hydrogen storages [1,2]. However, safe, efficient and cost-effective storage of hydrogen remains a major issue in this concept.

This study investigates the feasibility of a large energy storage with hydrogen as energy carrier onsite with a pre-combustion carbon capture and storage coal gasification plant and assesses the general impacts of such a backup installation on an electricity generation system with high wind power portion. The system consists of four main units namely the (i) coal gasification unit, (ii) ancillary power unit, (iii) main power unit and (iv) backup power unit including hydrogen storage. The integration of the hydrogen storage allows to store excessive energy under high renewable power output or low demand and to make use of the stored energy under low renewable power output or high power demand.

2. System overview

Two system configurations are analysed, which are similar over large parts and differ mainly in the way hydrogen is stored. Fig. 1 gives a simplified overview of the system. The difference between the two configurations is in the backup

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http://dx.doi.org/10.1016/j.ijhydene.2013.08.130

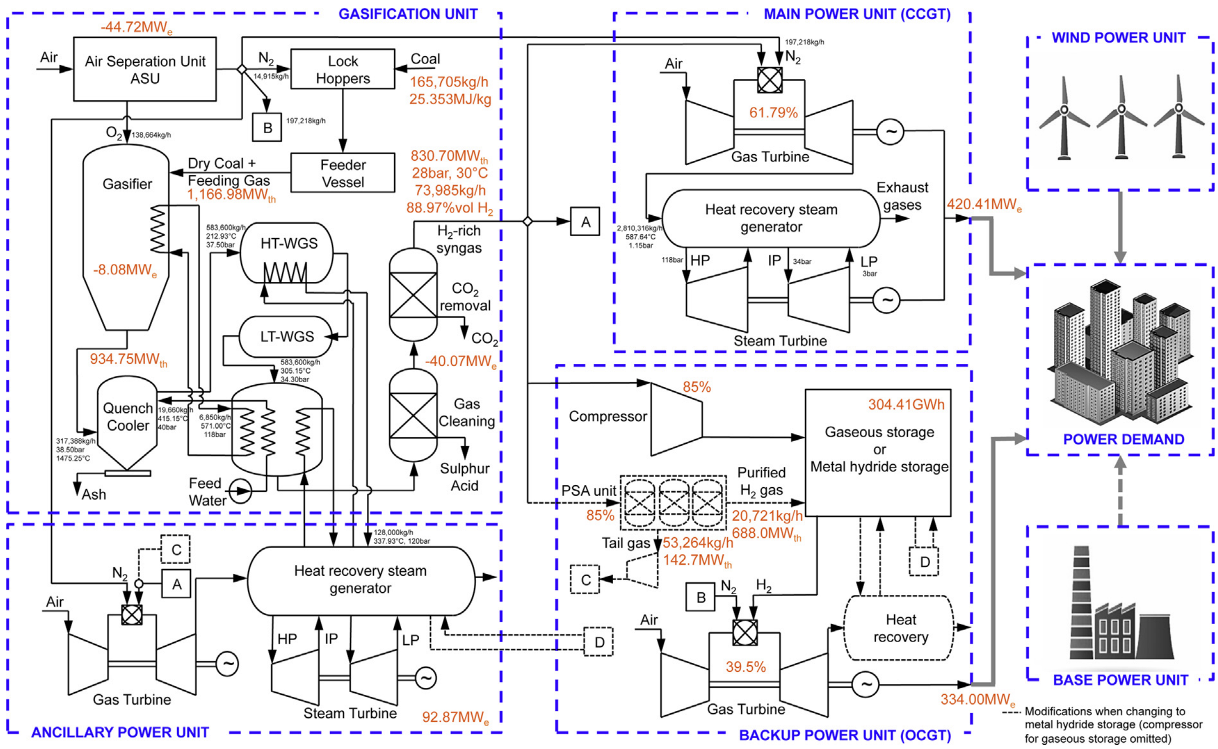

Fig. 1 – Overview of both system configurations *sys_gas* and *sys_sol* including design data (Par. 3.1).

power unit; the first configuration is based on gaseous hydrogen storage whereas the second one employs solid hydrogen storage in metal hydrides. The two system configurations will be referred to as *sys_gas* and *sys_sol* respectively. There is a wide literature on how each part of the system operates so only the differences between the proposed configurations will be discussed further.

The COAL GASIFICATION UNIT and the MAIN POWER UNIT are identical for the gaseous and solid system.

The BACKUP POWER UNIT differs between *sys_gas* and *sys_sol* hydrogen storage system configuration. The backup power unit for *sys_gas* mainly consists of a series of compressors, a modular gaseous hydrogen storage facility and a suitable OCGT. The backup power unit for *sys_sol* consists of a Pressure-Swing Absorption (PSA) unit, a tail gas compressor, a modular solid metal hydride storage facility and a suitable OCGT. The PSA unit is necessary to produce a high purity H_2-stream, which allows H_2 to be stored in metal hydrides without downgrading its functionality and cycling stability. Tail gas is compressed and used as fuel for the ancillary power unit for *sys_sol*. In both system configurations the H_2-based fuel stream is diluted with some N_2 in order to control flame temperature and NO_x-emissions. It should be also noted, that the two system configurations require different storage capacities, which is due to different properties and mass flows between H_2-rich gas and purified H_2. In order to complement, it would be also possible to include a PSA unit in *sys_gas* and to store pure H_2, but the distinction as above allows analysing the advantages and disadvantages when storing H_2-rich gas compared to storing pure H_2. In case of *sys_sol*, the metal hydride storage has to be conditioned due to the exothermic absorption and endothermic desorption characteristics of metal hydrides. Therefore, heat recovery is necessary from other heat engines of the system. To this, the heat recovery steam generator of the ancillary unit can be oversized as not just waste heat from its gas turbine is available, but also additional heat from the common heat exchanger of the gasification unit can be utilized. During extraction of hydrogen, heat can also be recovered from the exhaust gases of the backup power unit. Furthermore, it may be worth to think about an additional gaseous storage acting as buffer until the heat recovery is ready to supply heat for the hydrogen desorption process from the metal hydride. The conditioning of the solid hydrogen storage is a complex topic and depends widely on the utilized metal hydride sorption material. Also the continuous year-round conditioning of the metal hydride storage is challenging. Particularly in operation points where the gasification unit can be shut down, as then there is no remaining waste heat source of the system configuration in operation.

Different to most existing IGCC schemes with pre-combustion CCS is the complete separation of the ANCILLARY POWER UNIT in both system configurations. This maximises the co-generation flexibility of the plant. The ancillary power unit is efficiently realised by a CCGT. In *sys_gas*, the ancillary power unit meets the base load ancillary power demand of the gasification unit and is designed with flexibility to provide the electrical power to compress hydrogen if injected to the storage: for high flexibility, the ancillary power unit can be designed as 3 × 1 configuration with 3 gas turbines, 1 triple