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Safety study of a wind–solar hybrid renewable hydrogen refuelling station in China

Xiangmin Pan [a,*], Zhiyong Li [b], Cunman Zhang [a], Hong Lv [a], Shaojun Liu [c], Jianxin Ma [a]

[a] School of Automotive Studies, Tongji University, Shanghai 201804, PR China
[b] Institute for Energy Conservation, Jiaxing University, Jiaxing 314001, PR China
[c] Shanghai Sunwise Energy Systems Co., Ltd., Shanghai 201805, PR China

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ABSTRACT

The first renewable hydrogen refuelling station in China is under development for fuel cell vehicles. A safety study is conducted for the hydrogen station that consists of hybrid solar and wind power, integrated hydrogen generation and tube trailer delivery, hydrogen compression, hydrogen storage, and hydrogen filling system. Hazards associated with hydrogen systems are identified and typical failure scenarios are analyzed in terms of event probabilities and consequences severities. Safety measures and emergency responses are discussed. Results show that compressors are the major risk contributor and additional safety measures are required to reduce the hazards from the failure of compressors. Releases of hydrogen can result in either jet fire or flash fire depending on the time of ignition. From the consequence perspective, jet flame length determines the longest lethal distances and flash fire leads to the longest harm distances. To mitigate the risk of catastrophic tank rupture in fire events, all tanks must be cooled with flooding quantities of water. A safety distance of 6 m from the compressors would be appropriate during siting and location decision process, from the risk perspective. However, in the worst-case scenarios, a setback perimeter of 50 m is suggested to keep the public away from the accident scene.

Introduction

Hydrogen economy has been pursued for decades and one of the most promising fields is the application of fuel cell vehicles in transportation. Both the fuel cell and hydrogen industries are set for increasing gains due to renewed interest in a basket of drivers: control of emissions (both carbon and regulated); energy efficiency; and water use [1]. The increasing number of fuel cell vehicles will require more hydrogen filling facilities. According to a report from Pike Research, more than 5000 hydrogen refuelling stations for cars, buses and forklifts will be operational worldwide by 2020 [2]. It is observed not only the conventional hydrogen refuelling stations will be built but also more renewable hydrogen refuelling stations would be developed in the future. In China, a new renewable hydrogen refuelling station is under development in Dalian City with the support of the National High Technology Research and Development Program. Hydrogen in Dalian station can be produced by solar and wind energy, while the

* *Corresponding author*. 4800 Caoan Road, Tongji University (Jiading Campus), Shanghai 201804, PR China. Tel.: +86 21 6958 3850; fax: +86 21 6958 9355.
E-mail address: panxiangmin@tongji.edu.cn (X. Pan).
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previous hydrogen stations such as those built in Beijing and Shanghai were based on methane reforming or coal coking as their hydrogen source. The Dalian station will be the first renewable hydrogen refuelling station in China and expected to be a demo example guiding the development of hydrogen refuelling infrastructures in the future.

The safety issues of hydrogen are always a critical concern to the implementation of hydrogen facilities. Though hydrogen has been used in industry for decades, its civil usage in consumer's environment is relatively new. With the increasing number of fuel cell vehicles and hydrogen refuelling stations, both the general public and the emergency responders are facing new challenges due to the unfamiliar hazards of hydrogen that are different from those of petroleum fuels. Hydrogen has wide flammability range, low ignition energy and fast flame propagation velocity. Some properties may decrease the risks while some of them may increase the risks. The wide flammability range widens the gap between the lower flammability limits and stoichiometric mixture, making hydrogen more difficult to ignite near the lower flammability limit in the far field of a release. However, in the near field with high concentrations, the wide flammability range and low ignition energy increase will increase the probability of ignition, which is a disadvantage of hydrogen. Moreover, hydrogen is usually stored in hydrogen refuelling stations at very high pressure varying from 20 MPa to 87.5 MPa, which has the potential to rupture (or physical explosion, i.e depressurisation of the high pressurized hydrogen).

The safety concerns on the hydrogen infrastructures arose in both government authorities and research institutions in China in the last decade. As a result, a series of national codes and standards were published to regulate the safety of hydrogen infrastructures, such as GB50516-2010 Technical Code for Hydrogen Fuelling Station [3] and GB/T 31139-2014 Safety Technical Regulations for Mobile Hydrogen Refuelling Facility [4]. The promulgation of these national standards have greatly facilitated the development of hydrogen fuelling facilities and improved their safety in terms of siting requirements, layout plan, system operation and management, etc. Dalian station, as a type of hydrogen refuelling stations, should meet the general requirements defined in national codes and standards well. To achieve it, a safety assessment on the station is required during the approval process. More importantly, to guide the development of renewable hydrogen refuelling stations in the future, best engineering practice should be studied on the particular case of Dalian station, the first renewable hydrogen refuelling station in China.

Safety studies or risk assessments on different types of hydrogen refuelling stations have been carried out by many researchers all over the world to facilitate the development of hydrogen stations. Most of them are for conventional hydrogen refuelling stations and few case studies are for renewable hydrogen refuelling stations. UK researchers L.C. Shirvill et al. [5] performed safety studies on high-pressure hydrogen vehicle refuelling stations and investigate releases into a simulated high-pressure dispensing area. Japan researchers Shigeki Kikukawa et al. [6] carried out a risk assessment on a liquid hydrogen fuelling station in Japan and revealed the effectiveness and suitability of safety measures for liquid hydrogen fuelling stations through the use of the proposed risk matrix. Sun Ke et al. [7] did a risk analysis on mobile gaseous hydrogen refuelling station in China and assessed both the stationary and road risks of the mobile filling station. Jo Nakayama et al. [8] performed hazard identification for qualitative risk assessment on a hybrid gasoline–hydrogen fuelling station. As the result of their HAZID study, more than 300 accident scenarios were identified and safety measures for worst-case accident scenarios were suggested. Safety case studies on different type of hydrogen refuelling stations enrich our understanding of the safety of the new energy infrastructure and facilitate its implementation in the future.

Description of the renewable hydrogen refuelling station

The renewable hydrogen refuelling station is designed to fill hydrogen fuel cell vehicles to either 35 MPa or 70 MPa. The station is composed of hybrid wind/photovoltaic power generation system, water electrolysis hydrogen production system, hydrogen tube trailer, hydrogen compression and storage systems, and filling dispenser to fill the fuel cell vehicles. It is almost a microcosm of hydrogen economy that consists of hydrogen production, hydrogen storage and delivery, and hydrogen consumer applications. The major difference between the conventional hydrogen refuelling station and the renewable one is the energy sources for producing hydrogen. For the conventional hydrogen refuelling station, hydrogen is produced either from methane reforming or water electrolysis (electricity from coal) on site, such as the hydrogen refuelling station in Beijing, or produced in coking plants and delivered to hydrogen stations, such as the hydrogen refuelling station in Shanghai. For the renewable hydrogen refuelling station in this paper, the hydrogen is generated from on-site renewable sources including both solar and wind energy.

Fig. 1 shows the station layout. Hydrogen is produced by water electrolysis system located at the northeast corner of the station. Most of the electricity to power the electrolyzer is generated by the 120 kW wind turbines and the 50 kW photovoltaic installations that are located at the south and southwest of the station, respectively. Electricity from municipal power grid is served as a backup power for the electrolysis when the renewable electricity cannot meet the demand of hydrogen production. The compressors draw hydrogen to the storage tanks with pressure up to three different levels: 20 MPa, 43.8 MPa and 87.5 MPa. These storage tanks serve hydrogen dispensers as their hydrogen sources to fill the fuel cell vehicles to either 35 MPa or 70 MPa. A tube trailer with hydrogen storage pressure up to 20 MPa stands by as a backup hydrogen source in case of rush hours of high hydrogen demand in a short time. A flowchart of the station is shown in Fig. 2.

General hazards analysis of the station

Apart from the electrical hazard, the major hazards of the station are from compressed hydrogen. There are generally two types of hazards of compressed hydrogen. One is