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COLD ENERGY ECONOMY AND CYBERSECURITY OF FLOATING STORAGE AND REGASIFICATION UNITS: EMERGING TRENDS, CHALLENGES, AND OPPORTUNITIES

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Abstract. Today the world energy market is in great transition and the demand of clean energy such as liquefied natural gas (LNG). Increase of natural gas production and supply causes drawback of onshore infrastructure and many environmental restrictions. As solution, offshore large-scale terminals especially Floating Storage and Regasification Unit (FSRU) type is becoming commercially competitive and effective alternative for the areas where onshore gas supply infrastructure is not feasible. LNG production consumes around 850 kJ/kg of LNG energy and it is just dumped into seawater or in the atmosphere despite reusing as extra energy source. In this paper, we review the cold energy economy as well as current status of LNG cold energy utilization technologies. Moreover, current and emerging cybersecurity trends after LNG cold energy implementation at FSRU are proposed and discussed to broaden the perspectives of the researchers in the community and industry experts. Finally, the review concluded with a practical recommendation of implementation of LNG Cold Energy Hub concept for future energy systems.

Keywords: cold energy economy; LNG infrastructure; LNG cold energy utilization; energy efficiency; FSRU; cybersecurity

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1. Introduction

The growth of liquefied natural gas consumption predicts 1.3 % per year and it is 3.2 trillion m3 natural gas in 2010 to 5.2 trillion m3 natural gas in 2040 (Pospisil et al. 2019). The biggest consumers of LNG are Japan, China, South Korea, India, and Taiwan (IGU 2019). Confirming to British Petroleum (BP) statistics, LNG supplies will increase more than 15 % of total gas demand by 2040 overtaking pipeline trade (BP 2019). LNG is the second-largest traded commodity after crude oil and the value of LNG reaches over $150 bn. Looking to future prospective, natural gas (NG) supply form conventional reserves is enough for 55.1 years (185.7 trillion m3) and NG supply from non-conventional source (shale gas, tight gas, coal bed methane, aquifer gas, methane hydrates) is 845 trillion m3 (Pfoser et. al. 2016). These numbers of supplies reveal the stability of the LNG market. The development of non-conventional natural gas sources increases the demand for new LNG terminals projects. For example, Australia invested $200 billion for new seven LNG projects in the period of 2015–2020 (Schach et. al. 2018; IGU 2019).

According to the market prediction, the global demand for natural gas will increase about 2.1 % yearly to 2030 and a higher proportion for Asian countries (Faramawy et. al. 2016). Japan, China, and Korea were responsible for 55.5 % of the global LNG market in 2017. New ambitious suppliers launch in the natural gas market such as Qatar, Australia, U.S., and Russia, which increase natural gas export (Schach et. al. 2018).

Europe is an important natural gas player because of the strategic importance of gas resources to many European economies. The security of gas supply is composed of the EU energy balance and a wider energy security strategy. The concept of gas security is highly politized in the EU. Natural gas dependency in the EU reached almost 80 % in 2018, which surpassed 2017 by 5 % (Eurostat 2020). Furthermore, natural gas is crucial for the transformation of the European energy system and for meeting the EU decarbonization objectives (Green Deal 2020). The main goals, which influence the LNG market in the EU, are the global LNG revolution with the U.S. shale gas revolution and technological innovation as Floating Storage and Regasification Unit. The exploration of new natural gas sources and technologies, there are more possibilities to transport huge amounts of LNG by sea, which has changed the supply chain of natural gas (Landry 2020).

Extraction of natural gas from conventional and unconventional supplies, technological advance, diversification of supply chain, domestic policy factors get more fast spread of the LNG market especially in the EU (Schach et. al. 2018). Although, LNG demand increases, the development of technological LNG infrastructure has many challenges, which leads to future trading prospects and trends.

This review paper mainly focused on the emerging trends of liquefied natural gas cold energy utilization technologies and their potential development at FSRU terminals. In this paper, the current status of LNG cold energy utilization technologies, including electricity generation, desalination, cryogenic air separation, carbon dioxide capture as well as combined LNG cold energy utilization systems are first discussed. Then as a case study potential of cold energy economy and cybersecurity improvements of FSRU type LNG terminal in Western Europe are proposed. Finally, the review will be concluded with a practical recommendation of the implementation LNG Cold Energy Hub concept for future energy systems.

2. Development of LNG infrastructure and cold energy economy solutions

Today the world energy market is in great transition and the demand for clean energy such as liquefied natural gas, which increases rapidly. The main benefit of NG as fuel, that it could be used in all combustion processes to produce electrical energy, heat, and cold. Moreover, NG could be integrated into all types of vehicles for road transport, railroad transport, and shipping (Prospisil et. al. 2019). Natural gas/bio-methane/LNG vehicles are well-developed technology with a cost equivalent to petrol or diesel units and with cleaner exhaust emission. Comparing with traditional fuels, LNG emits 80 % less carbon monoxide, 70 % less mono-nitrogen oxides, 45 % less volatile organic compounds (Osorio-Tejada et. al. 2017). For the technical aspect, LNG-fueled trucks have a higher range (up to 700–1000 km), because LNG has a higher energy value (Pfoser et. al. 2016). According to the directive on the deployment of alternative fuels infrastructure (2014/94/EU) requirements, a regulatory framework for fuels is electricity, compressed natural gas, liquefied natural gas, and hydrogen.

EU has presented a sustainable energy security package and one of the priorities of this package is to improve LNG as an alternative gas source (Landry 2020). Promotion of the most efficient use of existing LNG terminals from a cross border perspective is considered. The growth of a new shipping route could greatly impact the long-distance maritime trade flow is one of the global economic and political relevance (Schach et. al. 2018). Development of LNG as the fuel of road transport is important to build refueling points approximately 400 km to ensure LNG road transport infrastructure as it is written in Directive 2014/94/EU.

International projects involve different sectors of LNG to communicate expanding the LNG market as a fuel source. Since now, major projects of LNG promotion as primary energy have been developing in the EU. For instance, the project "HDGas" is promoted by the Horizon 2020 European program which the main concept is the expansion of LNG as fuel for heavy vehicles. It is expected that the implementation of LNG as a fuel source in the Spanish road freight transport would reduce greenhouse gas (GHG) emissions by 12 % and diesel fuel consumption by 42 % in the long term (Osorio-Tejada et. al. 2017). The project "CORE LNGas hive" is introduced for increasing LNG fuel for transport in the marine sector of the Iberian Peninsula. On the contrast of other introduced projects, the project "CryoHub" is introduced to use LNG as a cryogenic fluid that is focused on large-scale cryogenic storage (Atienza-Marquez et. al. 2017). This project is also promoted by the Horizon 2020 European program.

The increase of natural gas production and supply causes drawbacks of onshore infrastructure and many environmental restrictions. As a solution, offshore large-scale terminals especially FSRU type is becoming commercially competitive and effective alternatives for the areas where onshore gas supply infrastructure is not feasible (Lee et. al. 2014). The other benefits of FSRU type are reduced cost, easier implementation, and regulatory approvals are less time-consuming doe to the lesser environmental impact comparing with onshore (IGU 2019; Laundry 2020).

FSRU type regasification unit is the most commonly used in the LNG market for several years. The floating storage and regasification unit capacity was 80.1 MTPA by the beginning-2019 of February. As of February 2019, twelve new offshore projects were under construction (IGU 2019).

According to the EU strategy aim for developing the potential of existing LNG terminals, the option could be LNG cold energy utilization systems integration in existing regasification terminals. LNG regasification is the final step of the supply chain in which LNG is transferred from liquid state to the gas and after that, it is supplying for consumers. During the regasification process, LNG releases a huge amount of cold energy which could be reused as an extra energy source in many processes (Choi 2013; Lin et. al. 2015). LNG cold energy is classified as waste cold according to the Cold Economy concept. The Cold Economy term is energy, which could be stored and moved as cold rather than converted into electricity and then converted again to provide cooling (Peters 2016). By Dearman analysis, LNG cold energy and financial potential of this approach has a positive impact and could add 33.24 Eur to the value of each tonne of LNG. This value increases by 10 % at the current price of LNG (The Cold Economy 2015). While LNG cold energy is verified such as financial potential, though, there are many limitations for the infrastructure of LNG regasification terminals. So, for these reasons, a lot of scientists and engineers are working on various projects to improve energy efficiency and cybersecurity aspects of regasification systems to utilize LNG cold energy and make them more flexible. The current innovations and LNG cold energy utilization technologies will be introduced in further paragraphs.

3. An overview of current status of LNG cold energy utilization technologies and economy

Cryogenic conditions mean that LNG is stored at -162 °C in special tanks when demand is to regasify and placing on the market. For economic prospective, long LNG storage has a negative impact on their quality, generation of losses, equipment depreciation so for these reasons, the better solution making efforts for rapid LNG realization. The extra profit and savings could be gained during the LNG regasification process. For instance, LNG requires regasification before transmission to the costumers, which is generally a heat transferring process with seawater or ambient air in the practice, 240 kWh/t of valuable cold energy gets wasted (He at. al. 2018). LNG cold energy consists of two elements in its utilization, which is "temperature energy" and "expansion energy" (Yamamoto 2012). Temperature energy is expressed as the temperature difference between LNG and the atmosphere and expansion process of LNG when it expands about 578–600 times in volume upon reach gas state (Gomez 2014).

There are many options to use LNG cold energy especially in large scale regasification units which demand huge energy for LNG vaporization (Kanbur et. al. 2017). The utilization of LNG cold energy could be direct (cold energy power generation, cryogenic air separation, refrigerated warehouse, manufacturing liquid carbon dioxide and dry ice, automobile refrigeration, automotive air conditioning, desalination of seawater) and indirect (cryogenic comminution and the treatment of filthy water) (Lian et. al. 2015; Kanbur et. al. 2017). Moreover, LNG cold energy could be used for deep freezing agro-food industry facilities or for space conditioning in the commercial and residential sectors as well as supermarkets and hypermarkets (Rocca 2010).

3.1. Electricity generation process

The electricity generation process is one of the most efficient patterns for recovering cold energy. Looking at the Cold Economy concept, the LNG cold energy could solve cooling issues, which would save more than 16 % electricity power production (Peters 2016). Since 1979 until now about 15 cryogenic power cycles using cold energy of LNG have been built in Japan (He et. al. 2018; He et. al. 2019). The LNG is an important fuel for gas turbine power generation units along the coast for its easy shipping transportation and storage (Chen et. al. 2017). LNG cold energy can be directly used as a cold source under the requirement of cryogenic conditions. On the other hand, the cold energy in forms of thermal and mechanical can be transformed into electrical power using power cycles (He et. al. 2019). The power generation process depends on special fluids, which absorb part of LNG cold energy and act as a coolant. Researches focus on investigating these fluid properties to find the best fluid for recovering cold energy of LNG. Other scientists focus on the development of combined heat and power (CHP) modular plants (Bao 2019). For example, (Rocca 2010; Messineo 2011) proposed a process, which used a cryogenic stream of LNG during regasification as a cold source in an improved CHP modular plant. Traditional power cycles integrating into LNG terminals have many limitations because of the small amount of generated power. As a solution, hybrid power plants as LNG/O2 combustion gas and steam mixture cycle, a hybrid power by oxygen liquefaction and LNG oxy-combustion and combine cooling, heating, and power (CCHP) system with the use of LNG cold energy are offered to increase generated power. Qi (2020) introduced power plants integrating into the regasification process of LNG with liquid air energy storage (LAES). Though, there are issues with the flexibility and safety of this system integration in the regasification process. Lim (2020) focuses on integrating the cold energy of LNG fuelled ships with power cycles. Despite this more studies have to be done to create equipment with the optimized efficiency and economy of this innovative system.

3.2. Seawater desalination process

Two-third of the world is freshwater and it is around 6 % of the world's water supply. Freshwater resources are becoming increasingly critical in different regions around the world because of the growing population, increasing consumption, rising anthropogenic activities, and climate change (Tagliabue et al. 2014). The seawater desalination process is an effective method to increase freshwater supplies in areas where a lack of freshwater supplies is. It could be done using different methods of the desalination process, but most of them consume huge amounts of fossil fuel, which generates emission of greenhouse gas and other desirable gases (Wensheng et. al. 2017). The option, which may reduce fossil fuel consumption, is freeze water desalination (FD). The freeze desalination with LNG cold energy utilization saves the cost of electrical refrigeration equipment and achieves energy savings and emission reduction (Cao 2015). Combining the two processes of LNG vaporization and seawater freezing may produce freshwater in an economical and environment-friendly way (Lin et. al. 2017).

In 1970-year, scientist Cravalho proposed a zero-energy theoretic system to recover LNG cold energy for freshwater production. Estimation of this system freshwater output is about 6.7 kg water /1 kg LNG (Kanbur et. al. 2017). Many scientists have been working on this LNG cold energy technology development as integrating extra power cycle in LNG regasification process, improvement of water treatment technology (Reverse Osmosis), special ice maker prototype or a flake ice maker (Wang 2012; Xia 2014; Lin et. al. 2017; Wensheng et. al. 2017). One of the best results was reached with (Wensheng et. al. 2017) seawater freeze prototype system. The results showed that the system capacity of freshwater reaches 150 L/h with the converted cold energy efficiency above 2 kg freshwater / 1 kg of LNG. The salt removal rate of the system is about 50 % and it is enough for one cycle of freeze desalination to produce drinking water.

Freeze desalination using LNG cold energy could reduce energy consumption, but there are many technological issues, that have to be solved. Though, innovative technologies such as HybridICETM and CryDesalination have been patented. These innovations would solve many technical issues in the future by integrating LNG cold energy facilities (He et. al. 2019).

3.3. Cryogenic air separation process

The cryogenic air separation unit consumes a high amount of energy to produce oxygen and nitrogen, argon traces with high purity. These elements are important for chemical technologies and industries. For instance, oxygen is used in metals production, chemicals, gasification, clay, glass, concrete products, petroleum refineries, and welding. Gaseous nitrogen is used in chemical and petroleum, electronics, metal industries. The third major component of air is argon, which is extremely important in welding, steelmaking, heat treating, and manufacturing processes for electronic (Ebrahimi et al. 2015). LNG regasification process provides a low temperature as cryogenic refrigeration source could be used in the air separation process which would be efficient and reasonable ways to utilize the LNG cold energy (Mehrpooya et. al. 2015; Xe 2014). When the technology of air separation integrated with LNG cold energy and this technology was applied to several engineering practices in Japan, Korea, France, and China (He et. al. 2019; Prospisil et. al. 2019). The air separation process (ASP), with a minimum temperature of -173.15 °C (feed air) available through the heat exchanging and it is the most suitable for the full recovery of wasted LNG cold energy (Fan et. al. 2015). Energy consumption with LNG cold recovery is about 38.5 % lower compared to a conventional cryogenic air separation process (Mehrpooya et. al. 2015). In advance, cryogenic air separation by LNG cold energy utilization technology will have a more positive impact on the system period of return in higher prices of electrical energy and lower prices of oxygen in the market (Ebrahimi et. al. 2017).

Though air separation by utilizing LNG cold energy has high energy efficiency, it is not recommended due to complex configuration and high capital investment (He et. al. 2019; Pospisil et. al 2019).

3.4. Innovations in carbon dioxide capture and use

For environmental issues as global warming effect and rising sea levels, a good option for LNG cold energy utilization is capturing carbon dioxide (Kanbur et. al. 2017). CO2 could be recovered and used in plants for increasing rates of photosynthesis. 2/3 of CO2 is used to produce urea, which is used in the manufacture of fertilizer and other products. Moreover, CO2 could be used in the food industry for freezing food, during food transportation, and for adding carbonation to beverages (Air Products and Chemicals 2009). Cement production is responsible for 5.6 % of emissions from fossil fuel and is the largest industrial emitter (Marjanovic et al. 2015). Monkman (2017) introduced a study for the CO2 utilization method in the production of ready-mixed concrete. An optimal amount of CO2 is injected during batching and mixing processes of concrete production. This method has many advantages for industrial-scale integration. In this case reduction of carbon footprint is up to 4.6 %.

Cryogenic CO2 capture could be a solution for CO2 utilization in various sectors where flue gases are thrown into the atmosphere. The flue gas could be condensed as a liquid phase or dry ice (Monkman et. al. 2017). Some researchers have been studied about capturing CO2 with LNG cold energy in LNG fuelled power plants. (Liu et. al. 2009) performed thermoeconimic analyses to optimize high-efficiency power and refrigeration cogeneration system COOLCEP-S (Cool Clean Efficient Power), which uses the LNG cold energy during the regasification process. One of the proposed CO2 capture strategies involves oxy-fuel combustion. Zhao (2016) proposed a novel system based on LNG cold energy utilization to capture CO2 in exhaust gas discharged from the magnesite processing industry located in Liaoning Province (China). This investigation was done, doe to the fact, that almost 4 million tons of CO2, which accounts for 1 % of total carbon emission in Liaoning Province is troughed into the environment. Liaoning Province has the largest magnesite mine resources of China (about 85.5 % of total China). The results showed that the LNG imported in Xianrendao Port could afford to capture CO2 from the magnesite system under specific conditions. The system can provide considerable electrical power (62.03 million kWh) as well as liquid CO2 products about 2.40 Mt per year. The CO2 captured from the magnesite processing industry can be supplied as a raw material for chemical production in Liaoning Province, such as methanol and fertilizer (Zhao et. al. 2016). Moreover, Chen (2017) presented a gas and steam cycle with a mixture of LNG/O2 combustion products and feed water as a working medium. The output power efficiency is based on the thermal value of LNG fuel 49.2 % and the equivalent net efficiency is 46.4 %, which is ¼ off-peak consumption for liquid O2 production (Chen et. al. 2017).

Despite that, cryogenic carbon dioxide capture by integrating LNG cold energy utilization could reduce the greenhouse gas emission, however, the uncertainty in the composition of CO2 in the flue gas is important to factor, which leads to the efficiency variation of the power plant (He et al. 2019).

The summary of the captured CO2 utilization methods presented below in Table 1.

Table 1. The summary of captured CO_2 utilization methods

Sector	Product	References
Biological Conversion	- Production biodiesel fuels from algae; - Component which increases growing of plants	Monkman et.al. 2017; Demirbas 2010
Chemicals and pharmaceutical processing industries	- Aerogels production; - Methanol production; - Production of small amounts of metal carbonates, bicarbonates, carboxylic sodium salicylate; - Solvent for many lipophilic organic compounds; - Dry cleaners; - Production of carbogen; - Added to medical O2 as a respiratory stimulation; - CO2 induction is used for the euthanasia of laboratory research animals.	Vessally 2017; Manjolinho 2012; Tan et.al. 2016; Tani et.al.2015; Bruder 2012
Concrete production	- CO2 recovering and rejecting into ready mixed concrete/Better quality cement	Monkman et.al. 2017
Dry Ice Blasting	- Cleaning and disinfection method for surfaces of equipment	Witte et. al., 2017
Enhanced Fuel Recovery	- A higher efficiency of Oil recovery; - ¾ injected CO2 remains in the ground (CO2 storage alternative)	IPCC 2005; Zhu 2011
Fire Suppression	- Fire Extinguishers	Air products and Chemicals 2009
Food/Products/ Beverages	- Carbonated soft drinks and soda water; - Acidity regulator (food additive); - Fermentation of sugars within the dough, chemical leaveners (baking powder and baking soda, wine); - Extractant for remove caffeine from coffee; - Wine production	Aydinalp et.al. 2011; Tsotsas et.al. 2011; Aminu et.al. 2017
Inerting Agent	- As compressed gases for pneumatic systems in portable pressure tools; - Carbon dioxide is used as an atmosphere for welding	Air products and Chemicals 2009
Mineral Carbonation	- Production of carbonates	Yıldırım 2014; IEA 2009; Mohamed et. al., 2017; IPCC 2005; Tan et.al. 2016
Miscellaneous	- CO2 injection into metal castings; - Dry ice pellets used for sand blasting; - Red mud carbonation	Air products and Chemicals 2009; Tan et.al. 2016; IPCC 2005; Tamm et.al 2017
Plastics	- Biodegradable plastics from CO2 and A class of compounds (epoxides); - Polycarbonates and polymers	Air products and Chemicals 2009; Aminu et.al. 2017
Refrigerant	- Dry ice; - Control of freezing temperatures; - Dry ice storage of ice cream and other frozen foods; - Automobile air conditioning	Peters et al. 2016

3.5. Other innovative projects

One of the innovative LNG cold energy utilization technology is a pilot project which was launched in Korea for hydrogen liquefaction. Hydrogen gas at ambient temperature is provided to be precooled by LNG and then feed into a closed-cycle Brayton refrigerator. Many experiments were done to improve efficiency, safety, compactness of this system, and the final solution was a 2-stage expansion cycle with LNG pre-cooling. It is identified as most suitable for hydrogen liquefaction with a capacity of 0.5 ton/day (Chang et. al. 2020).

Furthermore, the garbage incineration process could be combined with power cycles for the environmental aspect. Meratizaman (2010) offered to utilize the urban waste incineration cycle coupled with the cycle of changing LNG to pipeline gas. In this study, two new combined incinerator plants were applied in which LNG cold energy was used. For two new combined cycle's efficiency increased by 9 % and 17 % respectively (Meratizaman 2010).

Lian (2015) designed a process of cryogenic comminution of waste rubber using the cold energy of LNG. The results showed that using about 100 thousand metric tonnes of LNG every day in a regasification station, the first-level cold energy provided by the regasification station can produce 197 thousand of fine rubber particle per year and for reducing energy consumption, the second-level cold energy could be used to produce liquid CO_2 and dry ice. Waste rubber cryogenic comminution process consists of cooling rubber in temperature below the glass transition (-106 °C) and crushing process into fine rubber particles. Using LNG as cold source the waste rubber could be cooled below -115 °C in that temperature waste rubber crushes to make fine rubber particles. During this process, when LNG temperature increases from -162 to -100 °C, all cryogenic exergy could be fully utilized (Lian et. al. 2015).

Hereinafter, demand for data processing is increasing significantly, since more people become interconnected, work from distance. So, for this reason, digital communication is involving in their lives, the e-commerce market is growing as well. Data centers are among the 10 most unsustainable industries, due to their consumption of huge amounts of electricity. According to statistic reviews, about 700 million MWh of electricity is consumed by data centers per year and it leads 519 million metric tonnes of CO_2 equivalent emissions. Around 33 % of energy is used to provide cooling servers and systems which could be overheated in every moment. Hereby, exploitation by utilizing LNG cold energy by data centers could reduce greenhouse gas emissions and energy consumption (Ayachi 2019).

Moreover, one of the most profitable LNG cold energy utilization integration could be used for recovering heavier hydrocarbons (propane and butane). Yamamoto (2012) proposed the utilization of LNG cold energy applications in the LNG regasification plant. For example: to separate olefins and produced as a by-product at a neighboring oil refinery plant, to liquefy CO_2 and produced as a by-product at neighboring hydrogen manufacturing plant, to cool room-temperature butane refined at a neighboring petrochemical plant, to cool pure water used in inlet air coolers installed in gas turbine power generation plants (Dhameliya 2016). Gao et. al (2011), Wang et. al. (2014) were working on heavier hydrocarbons recovering from LNG. This technology has many advantages comparing with other LNG cold energy technologies because it is profitable if LNG contains heavier hydrocarbons (propane and butane).

LNG cold energy utilization technologies could be a part of the LNG market growing, which is identified by nearly 12 GW of LNG cold energy production (Prosposil 2019). Otherwise, integration has many potential risks events it is an ecological-friendly solution and the payback period is short. Cyber-physical security should be considered before doing the integration of LNG cold energy technologies in LNG terminals.

4. Cyber-physical systems at LNG terminals

Nowadays in our interconnected world cybersecurity has become the most important thing that influences every part of our life, especially regarding crucial infrastructure as LNG terminals (Limba 2017). The systems that are used are cyber-physical systems (CPS), as they integrate all the components, including sensors, communication services, and physical operations (Ashayeri 2016; Burgess 2019).

Upon beginning with the list of possible cyber threats and consequently cyber solutions for ICSs of LNG terminals, it is necessary to introduce the concept that is one of the pillars of cybersecurity. That being, that a system that guarantees the 100 % of security coverage is simply not possible: there is no control over the capabilities and motivations of cyberattack actors, and the goal of an effective cybersecurity management strategy is both to prevent an intrusion and to reduce eventual vulnerabilities. There are various classifications of types of cyberattacks but based on the three major objectives of cybersecurity, confidentiality, integrity, and availability, different types of cyberattacks can damage one of the three categories (UK government's National Technical Authority for Information Assurance (CESG 2015). In the case of LNG terminals, a cyberattack could mean the manipulation and readings of the plant's measures that could be used either to scam buyers, to hide a malfunction, or to alter the production process without it being registered. However, the majority of attacks have as cause the "human factor": either by paying employees to implant malicious codes via USBs or CDs or by responding to mail phishing and ransomware (Ashayeri 2016).

In the cyber-physical security system design by Ashayeri (2016), which is mentioned in the previous paragraph, are listed as a possible solution to cyberattack techniques in LNG terminals, the final part is crafted as a handbook that security managers can consult to strengthen the prevention to various kinds of cyberattacks. The classification is the following: firstly there are access problems, both from remote access and user access; in the first case, the recommendation is to implement specialized Virtual Private Networks (VPN) or Remote Access Servers (RAS), which would guarantee secure and encrypted connection channels, while in the second it is advised to enable Identity and Access Management (IAM) or Role-Based Access Control (RBAS) (Accenture Security 2018). The second type is classified as external security problems, such as Firewall\Network and purchased devices: in the authors' opinion, the reliability can be improved with Network Whitelisting devices, Application Monitors, and Industrial Protocol Filters. The last type of issue is the "employee" problem, or human factor, as aforementioned. In contrast, the intentional or unintentional sabotage of critical systems, training, and education is put as the only possible solution (Ashayeri 2016). Even though the aforementioned design offers a comprehensive look at management solutions to cybersecurity threats, there are a few elements that would need to be added to the whole picture. For what concerns the user access problem, blockchain technology is a worthy example of an "unbreakable solution", and it is highly recommended to strengthen the security of the system. Blockchain technology contains a public ledger of digital events that have been executed and shared among participating parties (Crosby 2016), and the technology allows data exchange without the need of a "third eye", or component that controls the successfulness of the transaction; applied to cybersecurity, the blockchain technology allows to protect the edge devices connected to the Internet of Things (IoT) and to ensure timely communication between devices located miles apart. In the case of employees that intend to voluntarily damage the system, a possible solution could be micro-segmentation, which can show each person what they are allowed to see based on their role and responsibility inside the company (Accenture Security 2018).

5. Floating Storage and Regasification Units: case study of LNG terminal in Western Europe

5.1. FSRU equipment, safety records and potential of LNG cold energy utilization

The floating storage and regasification unit consist of a berth (450 m length) and a gas pipeline (18 km). The terminal berth consists of three mooring points, six rope attachment points, servicing and high-pressure platforms, and connecting bridges. Special equipment has been installed on the berth, as fire safety towers and a fire extinguishing system, maintenance cranes, high-pressure loading arms, quick-detach rope hooks, electric generators, etc. The LNG terminal is connected to the natural gas transmission system. The maximum LNG regasification rate is 10.2 million Nm3 per day. The total capacity of LNG tanks is 170 000 m3.

Hazardous installations in FSRU are LNG loading/unloading pipeline, LNG storage tanks, LNG pumps, regasification equipment including LNG pipeline from tanks to regasification unit, boil-off gas (BOG) management system, and flexible LNG loading (unloading) hoses. FSRU contains four double insulated tanks with the inner hull.

The energetic and energetic analysis of FSRU was done to verify LNG cold energy utilization possibilities. The results showed that LNG cold energy utilization equipment could be integrated into several regasification units. The potential applications for maximum possible LNG cold energy utilization on FSRU should be cascade or hybrid systems, such as an example could be electricity production and cold generation in other sectors with different temperature levels needs.

Moreover, the special protection devices (temperature sensors, leak detection devices, LNG tank gauging with high/low-level alarms and shutdown systems, temperature, and density sensors) against LNG vapor release or explosion are installed in the tanks.

FSRU is protected against safety and security risks compliance with appropriate operational rules for ensuring a priority on safety. Moreover, FSRU is equipped with a number of sophisticated security systems as cameras, radiolocation, communication, and signalling security systems belonging to the Seaport Authority. Special Security services working around the ship to prevent not only terrorist attacks but also cyber-attacks.

5.2. Current and emerging cybersecurity trends

A future trend in cybersecurity is expected in the next few years, with the introduction of new experimental technologies such as 5G, quantum computing, Artificial Intelligence (AI) and Machine Learning (ML). These new discoveries will bring innovation in multiple fields but will also present a new type of risk concerning cybersecurity. The introduction of 5G technology is expected to raise the traffic capacity of 100 times more than the current one (Burgess 2019), updating the relatively new concept of the Internet of Things (IoT) to Massive IoT. The landscape overall is more than promising: amongst the more discussed elements, there is a decrease in latency, increase in connection density and the improvement in particular with the monitoring on millions of connected devices at the same time (Ivezic 2019), with the capacity of 1 million of connected devices per square kilometer (Burgess 2019). Since many LNG terminals are still relying on cable for communication systems, the perspective of gain real-time information and accurate monitoring is quite tempting. However, security measures need to be taken into consideration, since the parallel development of quantum computing represents a serious threat that all critical infrastructures are bound to face. In general, it is expected that quantum computing will be able to break 99 % of the encryption used to protect today's enterprises (Ivezic 2019). The "quantum threat" is becoming a potential cybersecurity issue, bringing to the enterprises and to private citizens the need for quantum-resistant strategies (Public Safety Canada 2018). Furthermore, there is a new type of cyberattack that is used effectively by more and more hackers: AI-based cyberattacks. AI algorithms are more successful in sending "spear phishing" tweets, with a speed six times faster than human-dependent attacks, as well as ransomware "machine-speed attacks" (Capgemini Research Institute 2019). The solution, in this case, could also be the implementation of AI-based cybersecurity: with AI going constantly going thorough data logs and incident timesheets, cyber analysts would be able to analyze more deeply the incidents identifies by the AI cybersecurity algorithms.

In terms of management of cybersecurity, these technologies are representing a new challenge, and even if LNG facilities are not considered priority terrorist targets by security experts (Mokhatab 2014), the integration with newer technology could force development of a comprehensive new strategy for cyber-security. Besides the training and education of the operators, newer techniques have been proposed as a possible solution to achieve a deeper securitization of the systems, such as the aforementioned quantum-resistant technologies, or more experimental solutions for cyber resilience like redundancy or digital twins. However, blockchain technology still represents the more favorable choice for protecting communication and access in commercial systems, but this could hypothetically change. The basis of blockchain technologies relies on the fact that is mathematically impossible to breach the system due to the reduced window of time. However, with quantum computing the cryptographic keys would be easy to crack in a reasonable time, although if we hypothesize that codes will not become stronger and harder to crack (Crosby 2016).

Conclusions

This paper reviews the state-of-the-art of LNG cold energy utilized systems including electricity generation, seawater desalination, air separation, carbon dioxide capture, and other innovative projects. Furthermore, this review proposes potential innovative applications for LNG cold energy utilization in the future.

To increase the energy efficiency of the whole regasification process, it is recommended to use cascade LNG cold energy utilization model for electricity production and cold generation for other sectors with different temperature levels needs. After the implementation of the cryogenic energy storage system in the Seaport area, the cold energy which is recovered from the LNG regasification process at FSRU, could be fully utilized and supplied for the wide range of users. In this case, FSRU could be exploited as a good practice of the LNG Cold Energy Storage Hub example.

In terms of management of cybersecurity, these technologies are representing a new challenge, and the integration with newer technology could force development of a comprehensive new strategy for cybersecurity.

The implementation of such improvement could increase energy savings, environmental benefits, and provide business opportunities creating new cold energy utilization plants or technologies.

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