2017 Young Researchers Awards

Finalists' Abstracts

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Modular and Extensible Interoperability IoT Hub for the Real-time management of the Smart Gas Grid

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During the past years, there has been a continuous growth and rapid evolution in the IT infrastructure of industrial/enterprise environment. This evolution resulted on powerful computers, smart connected devices, complex systems, enhanced networks, cloud computing, artificial intelligent, big data etc. Furthermore, the IT infrastructure has evolved from containing single monolithic systems to widely distributed heterogeneous systems such as Cyber-Physical Systems (CPS), Smart Devices, Internet of Things (IoT) systems, Industrial IoT systems, and Enterprise Application (EA). The integration and the collaboration between these heterogeneous systems results in a large complex system referred by System of Systems (SOS). The emerging smart environments, such as Smart Grids, Smart Gas network, Smart Cities, Smart Home, Future Industry 4.0, etc. are vital complex SOS that impact our daily lives.

Business rules drive the smart environment to achieve particular objectives. One of the objectives in the smart gas grid, that will assist in achieving the greenhouse gas reduction target, is to inject bio-methane in the existing grid. From IT point of view, real time management of the grid becomes an essential need in order to increase the enterprise competitiveness and make critical decisions. The real time management involves many distributed Information Technology (IT) and Operational Technology (OT) systems. An example of OT systems includes Supervisory Control and Data Acquisition (SCADA) architectures, Industrial control systems, PLC's, smart devices, etc. SCADA, for example, is a vertically integrated system for representing the vertical data exchange between equipment and Human Machine Interface. In a given environment, various SCADA, ICTS, smart devices and other monitoring and control solution may co-exist from different vendors, each with its own standard for accessing, manipulating, and representing data such as OPCUA, MQTT, radio transmission based network like Sigfox, etc.

Furthermore, many IT solutions such as enterprise applications (EA), simply referred by systems, coexist such as Enterprise Resource Planning (ERP), Geographic Information System (GIS), Computerized Maintenance Management System (CMMS), decision-support systems, logistic systems, and others. The heterogeneity of these IT and OT systems, due to different communication mechanisms, data format, and data semantics, makes the interoperable exchange of data very challenging, thus effecting the real time management of the grid. Some work groups steered their effort to solve this issue using particular standards. However, many research works had proved that using unified standard in smart environments are not sufficient. Other groups steers their effort to promote a holistic and a non-extensible interoperability solution.

As we are moving towards larger complex systems where millions of devices, applications and systems need to be integrated, the requirement for inexpensive/rapid integration solutions becomes an essential need. Thus, this work attempt to enable the interoperability between heterogeneous systems through the study and the development of a generic, conceptual, technically implementable, modular and extensible architecture that promotes re-usability at different interoperability levels (technical, syntactic and semantic), easily adapt to external system changes and does not impose a specific standard. It is applied in the context of a French national project called Gontrand to manage in real-time the quantity and the quality of gas at each injection point of the gas network.

Towards a sustainable future - the role of renewable gas in future Danish energy systems

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Denmark has set the ambitious goal of achieving an energy system, which is independent of fossil fuels by 2050. This implies that the Danish energy system will experience a remarkable transformation in the future, heading towards energy production based on renewable energy sources (RES), and stronger couplings and interactions between energy subsystems.

Today, Denmark self-sufficient with natural gas, and gas is a key energy carrier in the Danish energy system, accounting for 17% of the total energy consumption. However, given the Danish long-term energy policy targets, combined with declining gas consumption, and limited natural gas resources in the North Sea; answers to the crucial question of the role of gas and the gas infrastructure in a future Danish energy system is urgently demanded by the Danish gas sector.

This PhD project seeks to answer the emerging question and to contribute to the research field by developing energy system models, which can facilitate modelling of the integrated energy system including the power, district heating, gas, and transport systems. In this way, modelling of future effective, cost-efficient, and sustainable pathways towards future energy systems with high shares of RES can be facilitated. Specifically, the model of the future gas system includes renewable gas production, conditioning, transmission, storage, trade and use.

As a part of the PhD project, the role of renewable gas (RE-gas) i.e. biomethane, bioSNG, hydrogen and power-to-gas, in a future renewable based Danish energy system is investigated. To facilitate the modelling of renewable gas production, model developments in the generalized spatiotemporal network optimization model, OptiFlow, is undertaken. Furthermore, OptiFlow is hard-linked to the open source energy system optimization model Balmorel, allowing an integrated energy assessment of RE-gas production, storage and demand.

This framework enables detailed modelling of the chain from transportation of primary resources to renewable gas production plants, through storage facilities and to end consumers, while taking into account the spatial and temporal energy system integration. The co-simulation of OptiFlow and Balmorel leads to the socio-economic optimal system, where investments and operations optimization is facilitated for the integrated energy system.

The results of this study show that production of RE-gas is socio-economically attractive in all the investigated scenarios. Furthermore, results show that RE-gas directly injected into the natural gas pipeline network is preferred. The analysis show that geographical allocation of resources has an impact on the results. Moreover, the relationship between hydrogen production and electricity prices was identified.

Overall, this PhD project assesses the arising question of the future role of gas in an effective, cost-efficient and sustainable transition of the Danish energy system. Modelling frameworks developed in this PhD are open source, public available, and are developed in order to be applicable for other countries. This project provides future pathways for the Danish energy transition towards a sustainable future, with a detailed representation of the gas system as an integrated part of the future energy system, which is used to support stakeholders and policymakers in strategic decision making.

Hydrogen Blending into the Gas Distribution Grid: The Case Study of a Small Municipality

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Hydrogen blending into the gas network may offer an alternative concept for the storage of the exceeding energy from renewable power sources, improving the flexibility of the energy system through the integration of the electricity and gas networks. This scenario foresees the use of electrolyzers to convert power into hydrogen gas. The gas grid could both provide storage and act as the transport facility of the produced gas, taking advantage of the robustness and extensiveness of an already existing energy infrastructure.

In this work, a steady state and multi-species thermal-fluid-dynamic model of the gas network is applied to a portion of the Italian distribution network, located in Emilia-Romagna, covering a surface of 2,900 ha and having a throughput of 8.25 MSm3/year of natural gas.

The receiving potential capacity of the existing infrastructure is assessed with respect to hydrogen injection. Fluid-dynamic effects of the hydrogen blending are considered and commented.

The maximum allowable percentage of injectable hydrogen is calculated on a nodal basis, referring to the actual gas network configuration. The current Italian regulation on distributed injection (DM 19/02/2007) of gases into the natural gas network only allows injecting gases having nearly the same quality of natural gas (UNI-EN 437), thus excluding any blending practice. However, in the simulated scenario here proposed, it is assumed that gas quality requirements are on the network as a whole (i.e., after blending of hydrogen in the grid) rather than at the single injection point. By exploiting the quality-tracking feature of the model, the constraint of quality assessment at the injection point is thus relaxed.

Once the blending limit is known for each node, the amount of injectable hydrogen is calculated accordingly, taking into account the amount of natural gas already flowing through the node itself.

The node with the major injection capability is the designated one for the injection and used for the simulation of the case study.

Finally, a comparison between the 'base case' and the 'maximum hydrogen injection case' is presented and discussed showing how hydrogen blending into the gas grid may lead to a reduction on the fossil natural gas supply of up to 2,1%.

Phase Behaviour of (CO_2 + diluent) Mixtures in the Context of Carbon Capture

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Abstract

Biomass gasification is a key technology for delivering future low-carbon energy, both heat and electricity, as well as biofuels and other chemicals. If combined with carbon capture and storage (CCS), biomass gasification could potentially generate negative carbon emissions. Definitely the most expensive stage of CCS is the gas separation process, typically amounting to 80% of the total cost [1]. For the design, optimisation and safe operation of gas separation processes, accurate equations of state (EOSs) are required to describe thermodynamic properties of the various mixtures of relevant gases including CO_2, H_2, N_2, CH_4, Ar, CO and O_2. A popular and potentially very-accurate approach is to use empirical multi-fluid multi-parameter Helmholtz EOS models. In order to adjust the interaction parameters in those models, reliable and accurate experimental phase equilibrium data are indispensable, particularly vapour-liquid equilibrium (VLE). Unfortunately, there are gaps and significant discrepancies in the reported literature of experimental VLE data for mixtures of CO_2 with substances relevant in CCS. Discrepancies between literature sources are particularly noticeable in the vicinity of critical points.

In the present study, new VLE measurements have been made on two relevant systems: (CO_2 + CH_4) and (CO_2 + CO). The measurements were carried out on isotherms at temperatures ranging from just above the triple-point to just below the critical point of CO_2 and at pressures from the vapor pressure of pure CO_2 up to approximately 15 MPa or, if lower, the mixture critical temperature. All measurements were performed using the high-pressure low-temperature VLE apparatus described by Fandiño et al. [2], which is associated with very low standard uncertainties: 0.006 K for temperature; 0.003 MPa for pressure; and $0.011x(1 - x)$ for mole fraction x.

The new VLE data, together with earlier results from our laboratory on (CO_2 + H_2) and (CO_2 + N_2) [2], have been compared with the predictions of available thermodynamic models, including GERG-2008 [3] and EOS-CG [4]. Additionally, the data have been correlated with the Peng-Robinson EOS [5], generally incorporating a single temperature-dependent binary interaction parameter $k_{ij}(T)$.

The new experimental VLE data help to fill important knowledge gaps relating to the thermophysical properties of mixtures of CO_2 with substances relevant in CCS.

Improvement and cost analysis of the Power to Gas Technology by means of a process simulation

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Summary

Power-to-Gas (PtG) is a technology that provides flexibility to the renewable energy sources, as it enables the storage of the excess of electricity produced in a chemical carrier, such as methane. In this work, an approach is proposed to the design of an industrial plant that integrates both the carbon dioxide methanation process and the water electrolysis to generate the hydrogen needed for the methanation stage.

Methodology & Results

Aspen Plus V8.8 (Aspentech) software was employed for the simulation of the process and the sizing of the different equipments. The industrial plant design proposed can be divided in three different areas: i) water electrolysis process, ii) carbon dioxide methanation process and iii) condensation of the produced gas stream with the gas product being injected into the natural gas grid and the liquid product, mainly water, being recycled in the electrolysis process. A graph of the novel process is presented in Figure 1.

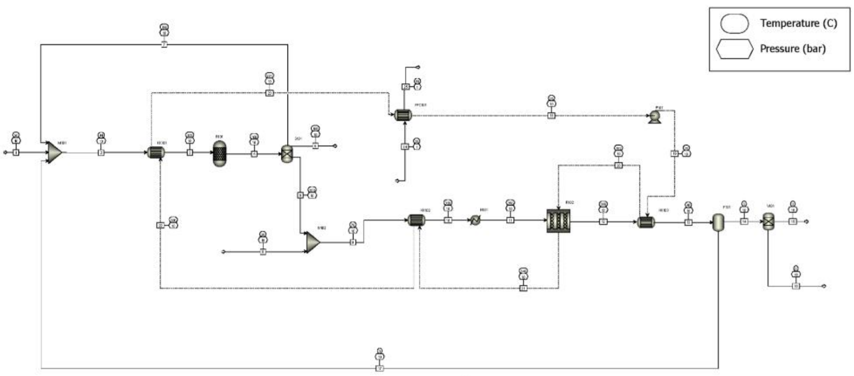

Figure 1. Process flowsheet

The chemical reactor was sized taking into account experimental data obtained from catalysts designed in the laboratory and data obtained from other authors [1]. The sizing of the electrolyser stack was carried out with data obtained from the bibliography [2]. Moreover, several heat exchangers were included to optimise the process.

Finally, an exhaustive cost analysis was carried out, studying the profitability of the process considering different criteria like time, cash and interest rates.

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Feasibility study of converting a Natural Gas Combined Cycle plant to a Power-to-Gas plant

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SUMMARY

At present, society, governments and institutions are more and more concerned about climate change. In an increasingly industrialised world is necessary to implement new policies both energy and environmental to continue to achieve a more sustainable world in the future. The European Union is aware of this and, in recent years, the Officers of the European energy policy have agreed on the increased integration of renewable energy sources in the energy system. This energy policy is not primarily only based on climate change aims and demands but also on the reduction of energy import dependency, on the increase of the domestic energy level, price stability and even the improvement of international image.

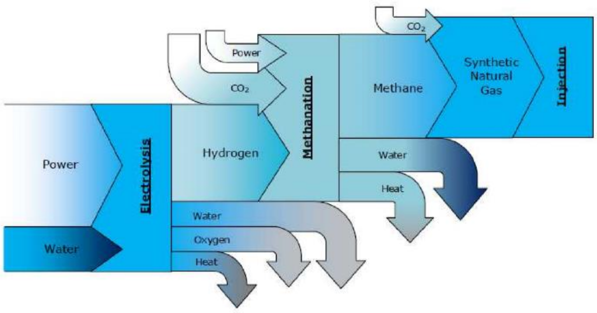

Figure 1 : Sankey diagram of PtG technology

The "Power-to-Gas" technology (PtG or P2G) consists of converting electrical energy (usually from intermittent sources like renewable energy systems) into chemical energy, producing renewable methane or renewable hydrogen (see Figure 1). These produced gases could be used to reconvert into electricity when the supply and the demand are not balanced, or as a heat source by combustion, or as a fuel in the area of mobility and so on. One of its main advantages lies in the fact that the product of the process (H2 or CH4) could be injected into the current natural gas network and, thus, it is not necessary to build new costly infrastructures for it.

The "Power-to-Gas" technology could be a valid solution to maintain in the future the functioning of natural gas Combined Cycle Power plants.

This project is based on this need, exploring new horizons being able to adapt to the new times which must undoubtedly advocate for a more sustainable and eco-friendly world. In this study the reader will find a brief explanation of PtG technology with the most current reviews; the document is contextualised with historical data and explanations on the gas and electricity market; the European policies on the environment have been analysed, as well as the technical viability of the conversion from one kind of plant to another. In this sense, an economic analysis of the plant has been carried out. Finally, a series of case studies are shown to see different application options.

2. METHODOLOGY AND RESULTS

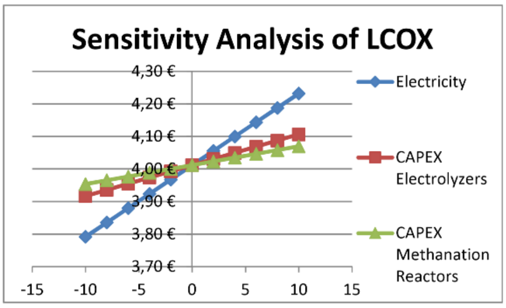

Figure 2 : Sensitivity Analysis of LCOX Power-to-Methane of *100Mwe*

Once the most updated information about this technology has been reviewed, a study about the necessary equipment and its cost were carried out.

The reader can realise that the feasibility of this technology is closely linked to the reduction of more than half of the current specific CAPEX in electrolyser and methanation reactors (see Figure 2), as well as the integration of the released heat of the methanation process into the global system and obtaining the lowest possible price of the input electrical energy, usually operating during the hours when electricity is cheaper. Besides, other results shown that producing hydrogen instead of methane is not the proper option based on the aim of reducing greenhouse gases.

Key words: Power-to-Gas, Environmental, Greenhouse gases, Climate change, Renewable, Sustainable, Feasibility.