Sustainable Industry Through Green Hydrogen Multi-sector Application: KoNSTantZE project

Feriel Mustapha
Technical Innovations
Institut für ZukunftsEnergie- und Stoffstromsysteme – IZES gGmbH
Saarbrücken, Germany
mustapha@izes.de

Bodo Groß
Technical Innovations
Institut für ZukunftsEnergie- und Stoffstromsysteme – IZES gGmbH
Saarbrücken, Germany
gross@izes.de

Frank Kruchten
Power Solutions, Manufacturing Engineering
Robert Bosch GmbH
Homburg, Germany
Frank.Kruchten@de.bosch.com

Michael Reinstädtler
Power Solutions, Manufacturing Engineering
Robert Bosch GmbH
Homburg, Germany
Michael.Reinstaedtler@de.bosch.com

Abstract
Cost-competitive and clean green energy is crucial for the realisation of the industry, mobility, and household realms. The global goal is to minimise carbon footprints worldwide and transitioning to sustainable energy sources, such us green hydrogen. The Bosch company – the global supplier of technology and services committed to climate neutrality status in 2020. Indeed, with the support of the German Federal Ministry of Economic Affairs and Climate Action, KoNSTanZE project was funded. The project concerned green hydrogen, from generation to final end use in the Bosch Homburg plant, in Germany. Actually, green hydrogen is used concurrently in several critical applications in the factory. For instance, in the hardening shop, for the facture of high-quality metallic products. Furthermore, KoNSTanZE project has provisions that involve storage, the mobility and transport sector. Indeed, a mobile hydrogen refuelling station and hydrogen stationary refuelling station have also been included in this project. Moreover, the components of the project are continuously monitored. The resulted data are managed and stored in the so-called Bosch Energy Platform. This platform, guarantees the functionality of the refuelling stations, and its safety. This study involves detailed data analysis employed method, aiming to provide insights into the effectiveness and efficiency of green H_2 production and utilisation, by examining various metrics and performance indicators.

Keywords: Green Hydrogen; Sustainable Industry; Renewable Energies; Data treatment and methodology

I. INTRODUCTION

Fossil fuels remain dominant in the global energy landscape with coal, oil and natural gas, representing 80% of global energy consumption. Thus, contributing significantly to greenhouse gas (GHG) emissions and climate change [1]. This dependency presents severely threatening impediments to attaining the global targets regarding climate change like Paris Agreement that aims at restricting the rise of global temperatures to well below 2°C [2].
To address these challenges, different measures have been planned to mitigate GHG emissions and foster sustainable energy transition. Indeed, the renewable energy sources including solar energy, wind energy and hydropower, which have become key subsectors of the global energy system [3]. Among which, hydrogen (H_2) has come to light as the most realistic solution to satisfy the energy requirements of the hard-to-abate sectors including industries, transports, and energy storages. Indeed, green H_2, generated through water splitting by electricity from renewable sources, is carbon-free which could be used for several applications, including industrial uses, power and energy and mobility [4]. As it is a clean energy carrier, which is paving the way in industry decarbonisation [5].
Given this, many programs have been launched internationally to unlock the green hydrogen potential and increase its usage. The Europe boldly has its strategy that maps how green H_2 goal will be achieved and hydrogen economy by 2050 inaugurated in Europe [6]. Likewise, the European Hydrogen Backbone is a plan to develop a direct hydrogen pipeline network for the distribution of hydrogen across the Europe [7]. And in accordance with such, Germany and precisely, Robert Bosch, as one of the world's major technology and services suppliers has been engaged in promoting green hydrogen technologies. As a matter of fact, the company reached climate neutrality in 2020, and has since progressed in the field of sustainable energy [8]. Notably via the KoNSTanZE[1] project, which is located in Bosch plant in Homburg, Germany. With the support and funding from the Federal Ministry of Economic Affairs and Climate Action, this project covers green hydrogen into industrial applications, power generation, and mobility [9].

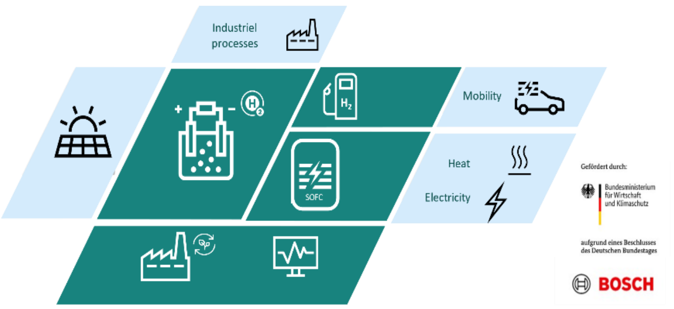

Fig 1 Layout of the KoNSTanZE project at Bosch Homburg (Source: Bosch)

[1] KoNSTanZE (Supported by: Federal Ministry of Economic Affairs and Climate Action (FKZ: 03EI3043A&B))

The KoNSTanZE project (see **Fig 1**) stands out in this context as not only the project delivers green hydrogen on site through renewable energy but also use it at various essential operations. At Robert Bosch Homburg plant, green hydrogen is used in the hardening as industrial processes. Also, as part of additional technologies, the SOFC (Solid-Oxide Fuel Cell) technology is applied in the project to turn the generated hydrogen into electricity and heat for use in the plant energy mix. In addition, the KoNSTanZE project targets the mobility sector under the establishment of both mobile and stationary filling stations. These stations facilitate other forms of mobility such as fuelling a vehicle fleet, industrial vehicles, as such, highlighting the effectiveness of green hydrogen in removing emissions in transport [8].

Unlike the other projects, KoNSTanZE has a comprehensive view and continuous supervision of all aspects of the green hydrogen value chain that is involved in the project. In the figure below, the project incorporates a photovoltaic (PV) array, a Proton Exchange Membrane (PEM) electrolyser, hydrogen storage systems, mobile and stationary refuelling stations, and industrial application such as the hardening shop.

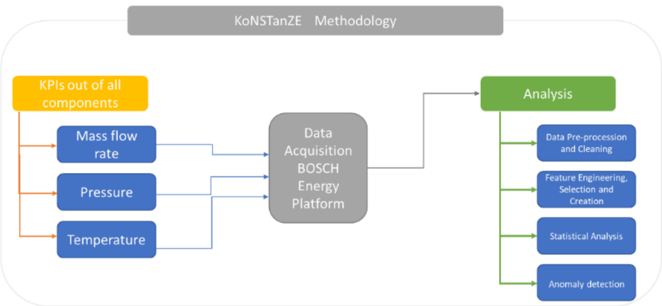

Fig 2 KoNSTanZE Methodology Workflow for Data Analysis

All of these components associated with green H_2 and its value chain, from production to final utilization. Indeed, the green H_2 is produced by the PEM electrolyser, which is power by photovoltaic. The KoNSTanZE project employs different monitoring approaches, which include monitoring of the critical parameters of the mass flow rate, the operating pressure and temperature. These are key performance indicators (KPIs) to weigh the efficiency, dependability and safety of hydrogen generation, storage and applications. Furthermore, existing literature includes several studies on the deployment and role of monitoring in managing technical and operational aspects, which are directly linked to safety and risk management. For instance, Gye et al [10] highlighted the importance of these measures to prevent real-world accidents likely in Santa Clara, California, and Oslo, Norway. Moreover, the current status of deployment and the role of monitoring represent a gap in the cohesive and systematic approach to the real-time production–storage–use. The present article is emphasizing the engineered process of analysing the data. More specifically, it encompasses the methods applied to analysis, assessment, visualisation, and comprehension of data. It is organised as follow, the next section details the methodology employed for data treatment, followed by the results and discussion. It also insists on the monitoring and data management; namely, the Bosch Energy Platform plays the role of data collector and data analysis for the operation of the refuelling stations as well as all phases of H_2 related business [9].

II. Methodology Data Collection and Modeling

The KoNSTanZE Methodology is a systematic approach which is employed through identifying the Key Performance Indicators (KPIs) of various components where mass flow rate, pressure, and temperature are considered as critical parameters. These KPIs are then collected through data acquisition in the BOSCH Energy Platform. The component on which the KPI are measured through sensors, are the electrolyser, the low-pressure tank, the compressor, and the mid pressure tanks, and finally the two refuelling stations the mobile and stationary.

The data that are collected through these sensors is then subjected to data pre-processing and cleaning to eliminate redundancies and irrelevant information respectively, to get the data ready for analysis feature engineering in order to increase the model's accuracy and statistical tests to reveal the existence of a relationship. The last stage, or the last procedure is the anomaly detection, which means that such behaviours which are unusually different from other data should be detected in order to examine and address them (See ***Fig 2***). The section below details the analysis and the process employed in the frame of the KoNSTanZE project.

A. Data Pre-processing and cleaning

The raw data collected often contains noise, missing values, and outliers that can adversely affect the accuracy of subsequent analyses. Therefore, data pre-processing is a crucial step. Missing values are managed using interpolation or imputation techniques, depending on the nature and frequency of the missing data. Outliers are identified using statistical methods for instance the Z-score.

$$Z\text{-}score=(X-\mu)/\sigma \qquad (1)$$

Where: X is the data point, μ is the mean of the dataset, σ is the standard deviation.

B. Feature Engineering, Selection and Creation

Feature engineering involves creating new features from the raw data that can improve the performance of the analytical models. In the case of KoNSTanZE project, the relevant features are mass flow rate, pressure and temperature differentials ($\Delta\dot{m}$,ΔP,ΔT) and derived the rate of change which are identified or created.

$$\Delta\dot{m}=\dot{m}(t)-\dot{m}(t-1) \qquad (2)$$

$$\Delta T=T(t)-T(t-1) \qquad (3)$$

$$\Delta P=P(t)- P(t-1) \qquad (4)$$

These features are essential for more advanced analyses like anomaly detection and time series forecasting.

C. Statistical Analysis

Statistical analysis is performed to summarize the data and explore relationships between variables. In this study, basic statistical metrics are applied, such as mean (μ), median, standard deviation (σ), and correlations between variables are calculated as captured in the equations below.

$$\mu = \frac{1}{N}\sum_{i=1}^{N} X_i \quad (5)$$

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i - \mu)^2} \quad (6)$$

Where N is the number of data points, and Xi is an individual data point. which are, in this case, referring to the key performance indicator already mentioned in this paper.

Autocorrelation: Autocorrelation function (ACF) is used to assess the correlation of the time series with its lagged values, which helps in understanding the time-dependent structure of the data.

$$ACF(h) = \frac{\sum_{t=1}^{N-h}(X_t - \mu)(X_{t+h} - \mu)}{\sum_{t=1}^{N}(X_t - \mu)^2} \quad (7)$$

Where h is the lag.

D. Anomaly Detection

Finally, anomaly detection methods are employed to identify any unusual or faulty behaviour in the hydrogen power plant's components. Anomaly Detection Techniques: Statistical methods (Z-score). These techniques help in identifying deviations from normal operating conditions, such as leaks or over-pressure.

$$Anomaly\ Score = Distance\ from\ \mu\ in\ terms\ of\ \sigma\ (Z - score)$$

Where: A higher Z-score indicates a potential anomaly.

Threshold Setting: Thresholds are set based on historical data, component characteristics and safety.

E. Algorithm Implementation

This structured approach to data treatment ensures that the data used in the KoNSTanZE project is robust, reliable, and ready for in-depth analysis. These steps described by the up cited equations are implemented and translated into a MATLAB scripting algorithm model. This last is ideal for handling large datasets and statistical analysis. MATLAB offers built-in procedures for data processing, including pre-processing, cleaning, and harmonization of data into usable forms such as mass flow rate, pressure, and temperature differentials. These functions allow for accurate trend identification and predictive analysis. MATLAB's statistical tools support correlation and autocorrelation analysis, while its efficient computation speeds enable real-time data processing. Its powerful visualization tools provide real-time monitoring and clear insights into system performance, aiding anomaly detection and analysis.

III. Results and Discussion

For this paper, the applications of the proposed method have been focused on the two mid-pressure tanks (MDs) of the test field. The following results illustrate the analysis carried out on pressure; data collected from these components.

Figure 3 shows the raw pressure data over a selected time period, for instance the June 24th, from 12h00 to 18h00. Clear trends and fluctuations are observable, particularly in the pressure data, where periodic increases suggest regular system activity which is equivalent to a filling process. While the pressure decreases for both mid- pressure tanks indicate that one of the final consumers is filled through the filling station. There are visible dips in both MD1 and MD2 pressures after 15h:00, with significant pressure drops. Post 16h:00, both MD1 and MD2 stabilise at around 430 bars for MD1 and 400 bars for MD2, respectively.

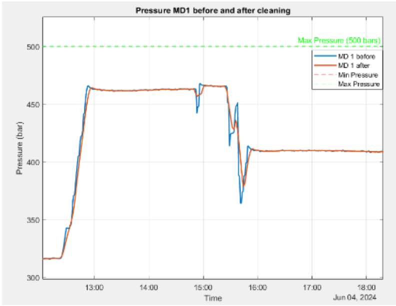

Fig 3 Raw Pressure Data for MD1 and MD2

Figure 4 and 5 shows the post cleaning data out of Mid pressure 1 and 2. The results demonstrate that the proposed method effectively captures the dynamics of the mid-pressure tanks, with the over-pressure detection algorithm. All values remain well within this range, and the data does not show extreme fluctuations, indicating that no significant outliers exist in this raw data. This first visual analysis concerns directly the safety operational mode of the plant. The cleaned MD1 (dotted purple line) & MD2 data (dotted yellow line), matches almost identically with the raw data, with very minimal difference. This suggests that the cleaning process did not significantly alter the raw data, as the pressure trends before and after cleaning are virtually identical. The cleaned data removes minor fluctuations, which are attributed to sensor noise.

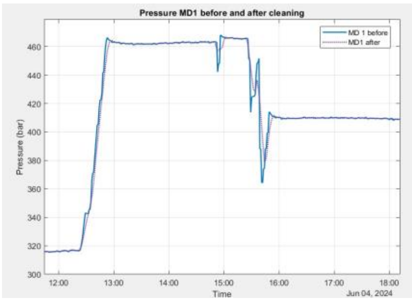

Fig 4 MD1 Pressure Before and After Data Cleaning: A Comparison

The first results highlighted from the KoNSTanZE project leads to the importance on the data provided by the sensors; which serves as a core performance indicator according to Genovese et al [11]. However, problems such as a variation in the accuracy of the sensors or inequalities in the calibration of the sensor have been reported. Based on his study, the actual hydrogen delivered might varied with recorded up to 35% due to the sensors [11]. This raises the concern on the reliability of other similar approaches when assessing the H_2 component. These sensor-related differences show that there are problems in developing an effective and safe process of hydrogen production. Optimization models depend much on the information needed for investment, impact and useful life of equipment's. Mitigation of these issues is crucial as hydrogen economy develops in the future.

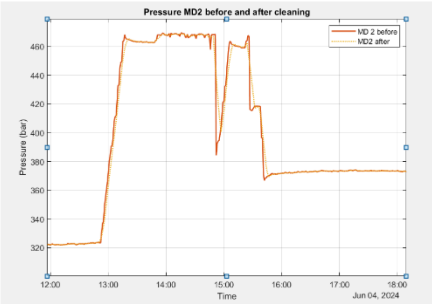

Fig 5 MD2 Pressure Before & After Data Cleaning: A Comparison

CONCLUSION

In this paper, the detailed data processing procedure for studying and analysing data resulting from operation of KoNSTanZE project. Indeed, data were selected according to KPIs and collected via Bosch Energy Platform. Pre-processing methodologies and transforming the features were implemented to a greater extent for cleaning the dataset. Using MATLAB for processing pipeline demonstrating that analysing large sets and identifying anomalies such as over pressures is possible. The use of statistical tools, feature engineering approach, and data visualization provided a comprehensive solution for assessing the plant safety and performance. It was found that data cleaning eliminated minor scatters due to noise in the context of sensor measurements. The presented approach is a good starting framework for the real-time condition monitoring and prediction of hydrogen power plants ensuring their safe and reliable utilization. In the literature, and as well in the present work the process is effective to diagnose faults once they have happened. Indeed, this real-time monitoring is incomplete for the early identification of problems like sensor faults. Further work will explore other plant components as well as improving the methods for the anomaly detection and creating predictive models based on the cleaned data. Applying machine learning models may improve the methods of predictive maintenance by analysing historical data to predict equipment's failure, thus cutting on operational time. Moreover, the development of a numerical twin for a more advanced fault detection and system performance optimisation.

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