MODEL OF ELECTRIC ENERGY STORAGE USING OPENMODELICA

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Abstract: The following work deals with power-to-gas, an electric energy storage technology that converts excess electricity produced mainly by renewable energy sources to synthetic natural gas. A model in OpenModelica is further presented. The model consists of a photovoltaic plant and its connection to the electric grid, as well as a model of electrical energy storage in batteries for purposes of comparison.

Keywords: Hydrogen; electrolysis; carbon dioxide; synthetic natural gas, batteries

1 INTRODUCTION

Renewable energy sources' penetration levels often increase, causing power generation to exceed the demand. Power-to-gas (P2G) plants convert excess energy produced mainly by solar and wind power plants and store it in the form of synthetic natural gas. The produced synthetic natural gas (SNG) can be then used for heating, transportation, long distance traffic or electricity generation [1].

2 HYDROGEN SUPPLY

Water is decomposed by applying electric current to produce hydrogen and oxygen, in a clean process known as water electrolysis [1]. Fig. 1 shows three different electrolysis technologies that are considered for P2G: Alkaline electrolysis, polymer membrane electrolysis and solid-oxide electrolysis.

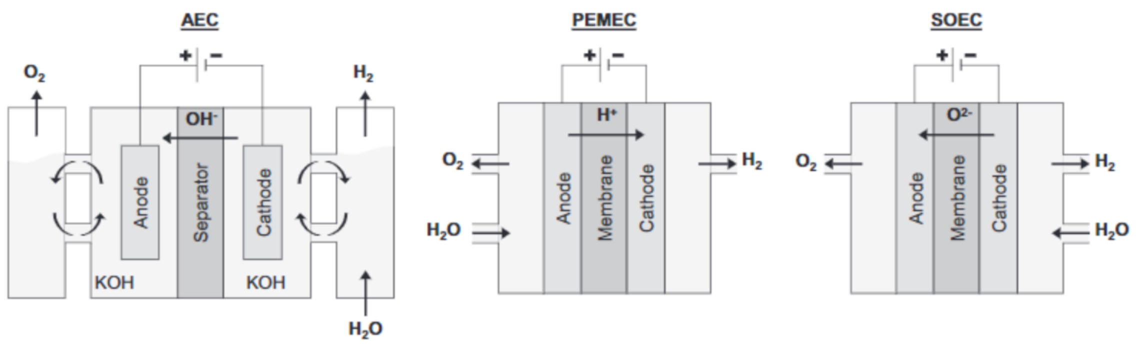

Figure 1: Set-up of three electrolysis technologies [2]

3 CARBON DIOXIDE SOURCES

The CO_2 required for the applications of P2G is produced from fossil fuels (combustion of natural gas, coal or fuel oil) or renewable sources (biomass or fermentation processes).

Carbon Capture Utilization and Storage (CCUS) In the case of the combustion of fossil fuels, carbon capture and consequently its separation are required. There exists 3 methods of CO_2 capture in combustion processes [3]: post-combustion, pre-combustion, and oxyfuel processes. Absorption, adsorption, cryogenics, membranes, and microbial/algal systems, are examples of separation technologies used.

4 METHANATION

The SNG produced in P2G plants must be have similar properties to natural gas. That is 80% CH_4 < 2% CO_2 and < 17 % H_2 [4]. Methanation can take place as catalytic as well as biological.

This methanation reaction works according to what is know as the Sabatier reaction. Chemical equation 1 shows the total reaction, while equations 2 and 3 show the sub-reactions.

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O \qquad \Delta_r H_{298} = -165 \mathrm{kJ/mol} \tag{1}$$

$$H_2 + CO_2 \longrightarrow CO + H_2O \qquad \Delta_r H_{298} = 41 \mathrm{kJ/mol} \tag{2}$$

$$CO + 3H_2 \longrightarrow CH_4 + H_2O \qquad \Delta_r H_{298} = -206 \mathrm{kJ/mol} \tag{3}$$

5 P2G'S CURRENT STATUS

There are over 153 P2G projects currently in operation around the world , with several huge projects now being built. Germany currently has the highest production rates, with a total of nearly 40 MW_{el} followed by Denmark 20 MW_{el} [5]. Data from multiple P2G projects and pilots from multiple countries are presented in [5], and they show production rates up to 10 MW_{el}, while the efficiency is around 41%. Being the world's leader in this technology, Germany is targeting a 5 GW of P2G capacity by 2025 and 40 GW by 2050. [6]. As for France, GRTgaz has performed its first injection of hydrogen into the gas grid as part of Jupiter 1000, a P2G project with 1 MW_{el} capacity and 25 m^3/h in methane production [7].

6 MODELLING AND SIMULATION

Fig. 2 presents the electrical part of the power-to-gas chain. Where electricity is produced from a PV station, further a DC/3xAC converter converts the produced DC voltage to 3x 400/230 V AC, which is then connected to the electric grid through a step-up transformer (22/0.4 kV), and is further transformed to feed the electrolyzers. Fig. 3 shows a detailed model of the PV plant presented in Fig. 2

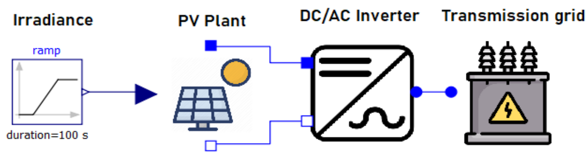

Figure 2: PV power station with connection to the grid

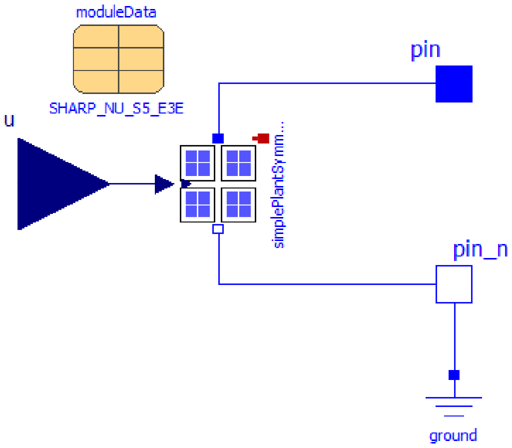

Figure 3: PV power station with an option of setting the number of series and parallel connected panels

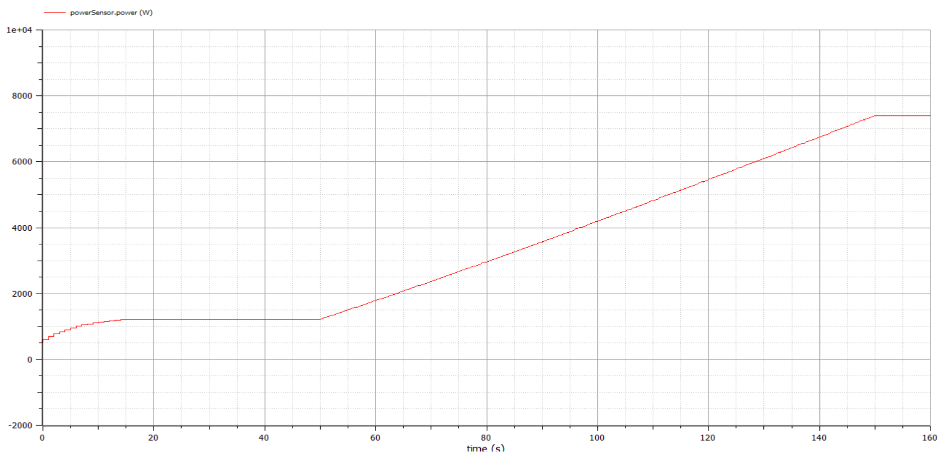

Figure 4: Output power of the PV power station

A ramp function detailing the irradiance over 160 seconds, where it's constant and then linearly increases after 50 seconds. With 40 series connected panels over one string for the chosen inverter model (DC150-1000V input, 3-phase AC400/230V output), The power produced reaches a max of 7401.6 W at 150 seconds. This is shown in Fig. 4. The chosen panel model panel is a SHARP - NU-S5 (E3E)-185 W, with a 7.71 A and 24 V at MPP [8].

$$V = 40 \cdot 24 = 960V \tag{4}$$

$$P = V \cdot I = 960 \cdot 7.71 = 7401.6W \tag{5}$$

Fig. 5 presents a model of energy storage in batteries. The DC-DC step-down converter, steps down the voltage produced from the PV plant mentioned above, while stepping up the current. A battery set of 25 series and 5 parallel strings, is then connected. As the state of charge increases with time, and simultaneously the voltage increases to reach 105 V for a fully charged battery set, the current gradually decreases (Fig. 6).

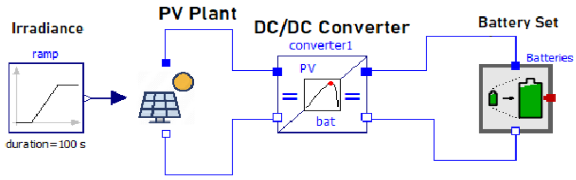

Figure 5: Electric Energy Storage in Batteries

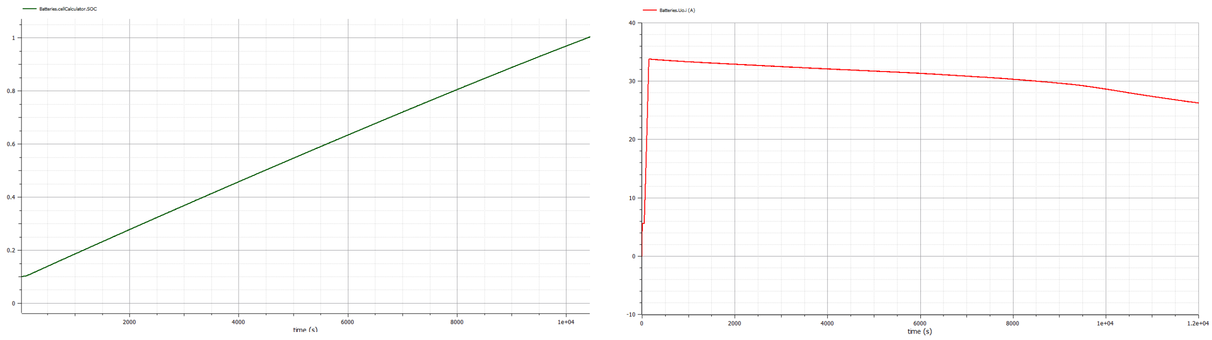

Figure 6: State of Charge (left), Current passing through the battery set (right)

Battery storage efficiencies are around 80-90%, while as stated above, P2G efficiency is around 40%.

7 CONCLUSION

Further work is set to be done on this model. To produce hydrogen, the electric current produced will be connected to electrolyzers and consequently methanation will take place. A more detailed model will include step-down transformers to be able to connect the electrolyzers. As well as methanation, calculation of synthetic natural gas produced and total plant efficiency.

REFERENCES

[1] GÖTZ, Manuel, Jonathan LEFEBVRE, Friedemann MÖRS, Amy MCDANIEL KOCH, Frank GRAF, Siegfried BAJOHR, Rainer REIMERT a Thomas KOLB. Renewable Power-to-Gas: A technological and economic review. Renewable Energy. 2016, 85, 1371-1390. DOI: 10.1016/j.renene.2015.07.066. ISSN 09601481. Available from: `https://linkinghub.elsevier.com/retrieve/pii/S0960148115301610`

[2] SCHMIDT, O., A. GAMBHIR, I. STAFFELL, A. HAWKES, NELSON a S. FEW. Future cost and performance of water electrolysis. International Journal of Hydrogen Energy. 2017, 42(52), 30470-30492. DOI: 10.1016/j.ijhydene.2017.10.045. ISSN 03603199. Available from: `https://linkinghub.elsevier.com/retrieve/pii/S0360319917339435`

[3] REITER, Gerda a Johannes LINDORFER. Evaluating CO2 sources for power-to-gas applications â“ A case study for Austria. Journal of CO2 Utilization. 2015, 10, 40-49. DOI: 10.1016/j.jcou.2015.03.003. ISSN 22129820. Available from: `https://linkinghub.elsevier.com/retrieve/pii/S2212982015000244`

[4] STANGELAND, Kristian, Dori KALAI, Hailong LI a Zhixin YU. CO 2 Methanation: The Effect of Catalysts and Reaction Conditions. Energy Procedia. 2017, 105, 2022-2027. DOI: 10.1016/j.egypro.2017.03.577. ISSN 18766102. `https://linkinghub.elsevier.com/retrieve/pii/S187661021730629X`

[5] THEMA, M., F. BAUER a M. STERNER. Power-to-Gas: Electrolysis and methanation status review. Renewable and Sustainable Energy Reviews. 2019, 112, 775-787. DOI: 10.1016/j.rser.2019.06.030. ISSN 13640321. https://linkinghub.elsevier.com/retrieve/pii/S136403211930423X

[6] Power-to-gas industry in Germany to experience massive boost in the next five years [online]. Hydrogen Fuel News, 2019 [cit. 2020-03-06]. DostupnĂ© z: http://www.hydrogenfuelnews.com/power-to-gas-industry-in-germany-to-experience-massive-boost-in-the-next-five-years/8539003/

[7] France: GRTgaz Performs the First injections of Hydrogen into it Networks [online]. FuelCellsWorks, 2020 [cit. 2020-03-06]. https://fuelcellsworks.com/news/grtgaz-performs-the-first-injections-of-hydrogen-into-its-network/

[8] Sharp NU-S5(E3E) [online]. pvx change [cit. 2020-03-12]. https://www.pvxchange.com/en/sharp-nu-s5e3e-2104883