Modelling one year of operation of PV supported electric supply of a district with H2 storage

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SUMMARY OF THE ABSTRACT

Considering that energy storage is an essential component in renewable energy systems, this work investigated the introduction of a hybrid BIPV and hydrogen-storage system approach for a district development project at “Kempelenpark" within the scope of the national funded research project "Vitality District" in Vienna (Austria). The analysis considers both the BIPV design for a structurally optimal use of the solar resource, and the use of hydrogen via electrolysis for peak clipping and storage. This work compared various optimization strategies aimed at finding the optimal capacities for the components of the hydrogen storage system both from a technical and economic point of view under some specific constraints. The potential to supply the district’s electricity needs (at Kempelenpark) [1] was determined in various case scenarios (see Figure 1).

In this study, a MATLAB model for the joint operation of the BIPV systems (ring grid), central storage via electrolysis and hydrogen storage as well as re-electrification with fuel cells was developed. With a total gross floor area of 135,000 m2, the design of the PV systems in total was 690 kWp roof systems (15° inclination) and 952 kWp facade systems (90°) with 50% technical use of space (through windows and greening). The design was carried out with PVSITES in one strand per facade and floor.

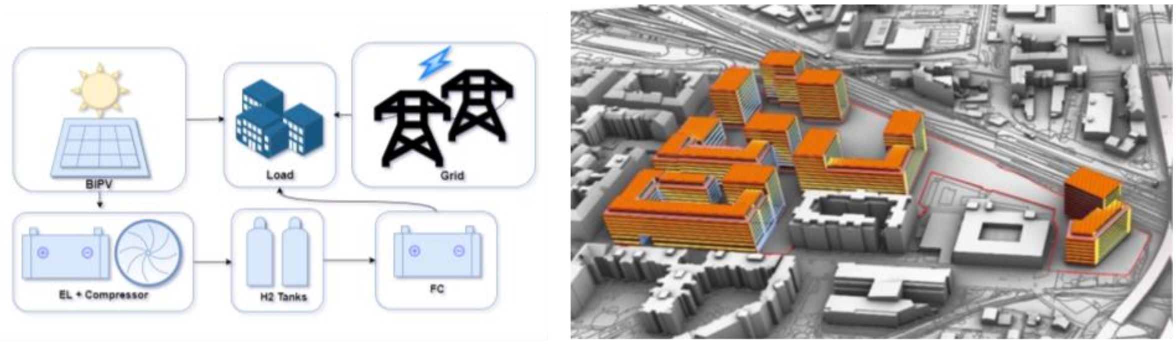

Figure 1: Left: System scheme of the simulation: PV systems, central electrolyser, hydrogen tank, fuel cell, building loads (ring grid) and external grid; Right: Architectural master plan for the "Kempelenpark", Vienna.

APPLICABLE TOPIC AND SUB-TOPIC NUMBER

Topic 5. PV in the Energy Transition

Subtopic 1: Energy System Integration; Resilience and Security of Supply; solar fuels, Stortage

EXPLANATORY PAGES

AIM AND APPROACH

PV modeling:
The modeling was done for the individual buildings in the master plan of the current planning status 2022. 22 kWh/m2 and year for purely electrical consumption and 31 kWh/m2 and year including heating and cooling were assumed as the basis for average consumption for all buildings. This allowed the entire coverage level to be determined. In a more detailed analysis, the potentials of the individual buildings could be put in relation to individualized consumption. According to the above-mentioned method, the facades (all sides: South, East, West and North) and roofs were covered with photovoltaic panels (roof: 290 Wp monocrystalline PERC with 5.82 m2/kWp and facade with 460 poly-crystalline with 6.12 m2/kWp).

Electrolysis system:
In order to increase the degree of self-consumption and to reduce the grid consumption, electricity storage was simulated. The choice fell on H2 electrolysis with low-pressure storage and re-current by means of fuel cells, since both a short-term storage and a potential long-term storage is possible. The capacity of the electrolyser was chosen to use 90% of the maximum surplus of PV (PV yield minus load) - a maximum of 10% of the maximum surplus of PV production went into the grid. The maximum congestion for PV was 5%, the loads were synthetic load profiles. The efficiency of the electrolyser (PEM type) is assumed to be constant and is 65% (EE-to-LHV) [2]. The efficiency of the fuel cell was chosen with 50%.

SCIENTIFIC INNOVATION AND RELEVANCE

The main innovation lies in several aspects. (1) While dimensioning of PV-facilities also in-built environment as well as hydrogen electrolysis is well known, the innovation lies in the coupled simulation of both. (2) The approach was to technically realistic design the components (including cost calculations, which are not show here) which is not a technical maximal strategy. (3) Finally, while exiting fossil gas is a definite strategy in European cities as also Vienna, no concrete plan for replacement of annual and daily fluctuations in electric supply is counter acted. This work gives one route for approaching this topic on district level. (4) General solutions were shown that by optimization several goals may be achieved in future energy planning: lowest costs, lowest grid-consumption, lowest grid feed-in or highest self-sustainability.

RESULTS (OR PRELIMINARY RESULTS) AND CONCLUSIONS

PV yields: The yields of the PV are shown in Figure 2. In the district, a total of 925.5 MWh of electricity can be generated from roofs (490 MWh) and facades (435 MWh), which corresponds to about 31.3% of the electrical load (without heating and cooling 2.961 MWh). The component optimization was carried out for hourly values of the annual cycles of load and generation.

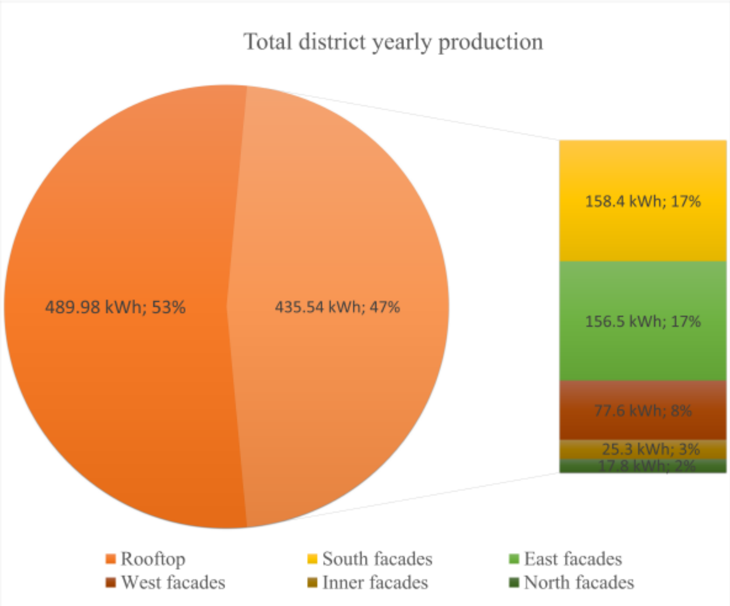

Figure 2: Yields of the roofs and facades. The facade fractions for different cardinal directions are summarized again.

Electrolysis system: The performance of the H2 electrolysis resulted in 657 kWel and 665 kWel for the fuel cell. The maximum power supply of the load was calculated with 85% as possible. 24% of the total production can then be stored in the form of hydrogen, which was used by the fuel cells for load shifting and peak capping.

System optimisation strategies: Two major optimization strategies were pursued to assess the system components. The first was achieved by fixing the electrolysis capacity and adapting the other system components to the 90% self-consumption scenario, see above. The second strategy considers the entire system components as variables and looks for the minimum values for the components that meet the above system limitations.

(1) Fuel cell optimization: The simulation for the optimum fuel cell capacity showed a capacity of 310 kWel for the fuel cell with the same electrolysis capacity compared to 664.9 kW for the optimization case for hydrogen storage. Furthermore, 4700 kgH2 was found for the hydrogen tank capacity (77.6 MWhel). This means that more hydrogen has been stored in the tank and the delivery can be distributed over more time. Figure 3 shows a week at the beginning of "April" exemplary for the use of the generated energy, as well as the load coverage by PV, fuel cell and grid.

(2) H2 tank optimization: In the second central case of component optimization, the H2 tank was optimized. In case of optimization of the H2 tank capacity, the fuel cell was fixed with 665 kWel and the H2 tank resulted in 4400 kgH2 (72.6 MWhel). This is only slightly lower than in the fuel cell-optimized case.

The optimization scenarios result in overall optimized capacities. The electrolysis capacity was defined by the need to be able to absorb 90% of the PV yield peaks of production over the load throughout the year. The fuel cell has been optimized to be smaller than originally designed for longer re-current periods and compatible with the maximum approved grid reference over the year. The hydrogen tank capacity was approximately the same in all scenarios and the optimum values were: H2 electrolysis system: 657 kWel, fuel cell: 310 kWel and H2 tank capacity: 4420 kgH2.

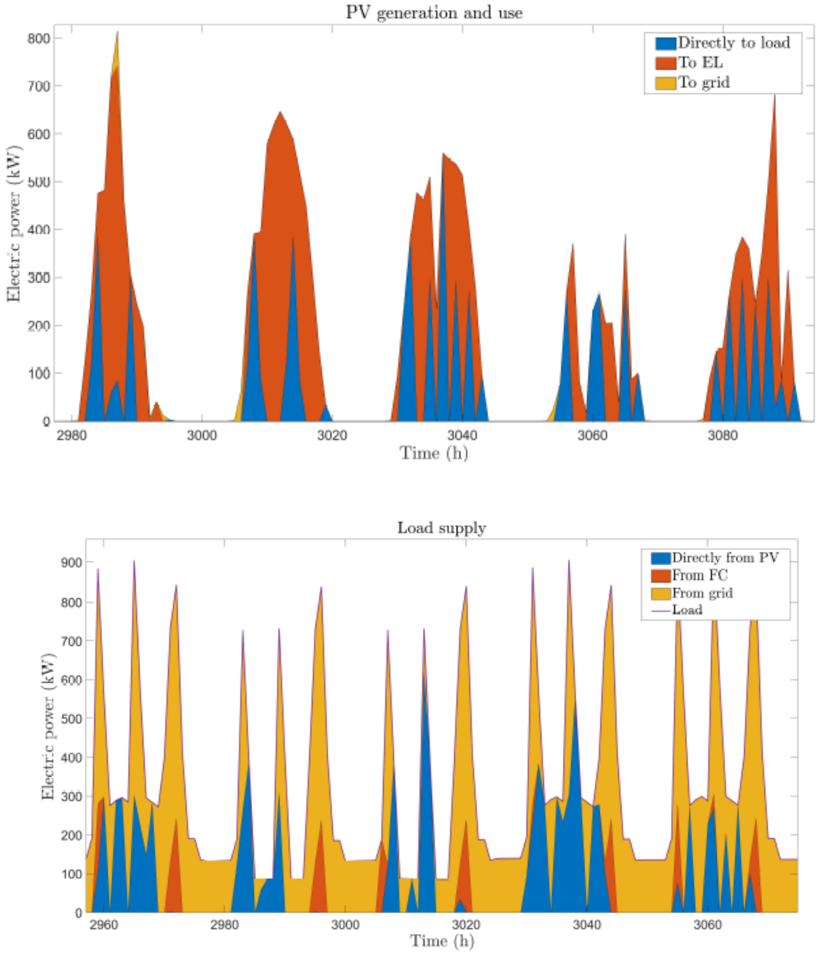

Figure 3: Fuel cell optimized operation for an exemplary week in April and synthetic load profile. Above: Generation and use of the PV power directly to load - blue, to electrolysis - orange and into the grid - yellow); Below: load coverage by PV (blue), fuel cell (orange) and grid (yellow).

Summary

The work showed that the electricity generation for districts by PV on the roof and in the facade can achieve meaningful, significant fractions, and that self-consumption can be increased technically meaningful by storage with hydrogen. The architectural design of the buildings with regard to solar potential can significantly increase the electricity generation from photovoltaics within the framework of the district. It could be shown that technically realistic solar activation of all buildings in a district (facade and roof) (1) can be in line with other measures such as lighting and greening (2) can make a significant contribution to the reduction of grid consumption (3) Hydrogen represents a feasible possibility for peak load reduction and feed-in management in interaction with the grid.

References:

[1] Vitality District (2016) . https://www.amkempelenpark.at/page.
asp/-/projekt.htm, 2022.
[2] Design of hybrid powerto-power systems for continuous clean pv-based energy supply. International Journal of Hydrogen Energy, 46(26):13691-13708, 2021.