

SUPPLY OF SOLAR ELECTRICITY TO UNINTERRUPTIBLE LOADS VIA SEASONAL STORAGE WITH POWER-TO-POWER SYSTEMS

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Abstract - In the framework of power sector decarbonization, this work aims at designing a Power-to-Power (P2P) system that allows to supply a given fraction of self-generated electricity from a solar photovoltaic (PV) plant to an uninterruptible 1-MW constant load. A model is set up to size the system components optimizing the annual operation, with the goal of minimizing through a MILP approach the annual average cost of supplying electricity to the load. Results show that, with the present cost of grid electricity and the present investment cost of the P2P system components, the installation of a P2P system able to supply 100% of the demand is not advantageous and the best solution in terms of average electricity cost is obtained by self-generating nearly 30% of the load annually with a simple PV plant. At any rate, to reach high share of self-generation the P2P system becomes mandatory to decouple generation and consumption on both daily and seasonal scale.

Index Terms – Energy storage, Hydrogen, Power-to-Power.

I. NOMENCLATURE

EE	Electric Energy
EL	Electrolyzer
FC	Fuel Cell
P2P	Power to Power
PV	Photovoltaics

II. INTRODUCTION

The decarbonization of the power sector plays a crucial role in the reduction of greenhouse gas emissions, mainly achieved by use of renewable sources. In this framework, this work aims at designing a system that allows to power an uninterruptible 1 MW constant load with electricity from a solar PV plant. Since PV power generation occurs only during daytime and is higher during summer, a Power-to-Power (P2P) system able to decouple demand and supply on both a daily and seasonal scale is considered.

III. SYSTEM CONCEPT AND LAYOUT

The P2P system includes a PV plant, an electrolyzer,

pressurized hydrogen tanks and a fuel cell. The system components as well as the energy and hydrogen flows are schematized in Fig. 1. The electricity demand of the uninterruptible 1 MW load is satisfied partially by the PV plant (directly or through the P2P system) and partially with power taken from the grid. The instantaneous share of these two contributions varies at each time step and influences the annual share of self-generated renewable energy on the total demand.

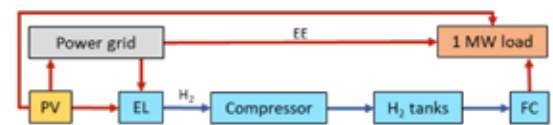


Fig. 1. Schematic of the system components and energy flows.

Given the specific generation of the PV plant, a model is set up that sizes the system components by optimizing the annual operation, with the goal of minimum average cost of the electricity annually consumed by the load. The problem is solved as a mixed-integer linear programming (MILP) optimization problem. Investment cost assumptions take into account recent cost evaluations of the main components [1]: 1000 €/kW_{el} for PV, 1000 €/kW_{el} for EL, 400 €/kW_{el} for H₂ compressor, 600 €/kg for H₂ tanks, 4000 €/kW_{el} for FC. A 10 %_{year} capital recovery factor is considered. Electricity is bought from the grid at a price that varies from 175 to 187 €/MWh_{el}, depending on the hour of the day and the day of the week. Electricity generated by the PV field and not supplied to the load or to the EL is sold to the grid at 60 €/MWh_{el}.

IV. RESULTS

Assuming that the P2P system is located in northern Italy (Milan), the average annual cost of electricity provision to the load is firstly optimized considering the share of self-generation as a variable, obtaining the 'best' case solution: installed PV capacity equals to 2.81 MW_p and no P2P or other components are present, resulting in a self-generation of 29% on an annual

basis. Thus, installing a PV plant is proved economically preferable to simply buying all the required electricity from the grid (reference case).

A sensitivity analysis is then performed, increasing the minimum annual share of self-generation that the system must guarantee. Up to 38% self-generation, the P2P system is not installed since increasing the size of the PV field (that reaches 8.56 MW_p at 38%) results less expensive. Above 38% self-generation share, the P2P system becomes necessary to decouple generation and consumption. Fig. 2 shows that in the range 40%-80% the electricity flows from PV to P2P and from the P2P system to the load increase at a nearly constant rate. On the contrary, the PV-generated electricity sold to the grid remains approximately constant, because the additional PV is installed only to supply the load. These trends change above 80% self-generation, where the FC installed capacity reaches its maximum. In this range, a steeper increase in the size of the PV field is observed (see Table I) and above 90% also the total size of the hydrogen tanks increases faster (tripling its value when moving from 90% to 100%), highlighting the need of a very large storage capacity for a full seasonal energy shift.

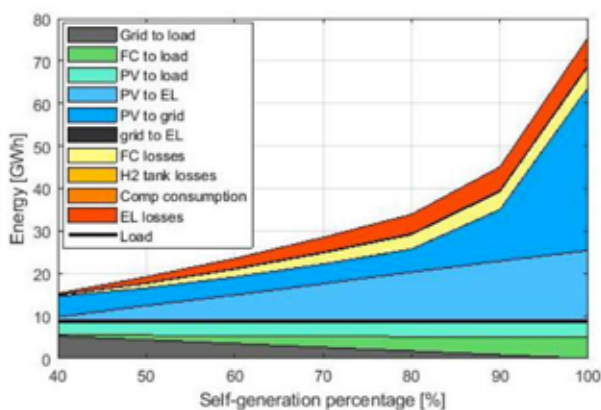


Fig. 2. Energy flows for increasing annual self-generation share in northern Italy.

TABLE I

INSTALLED CAPACITIES OF P2P SYSTEM COMPONENTS IN NORTHERN ITALY

Self-generation percentage		50%	60%	70%	80%	90%	100%
PV	P _{nom} [MW _p]	8.67	10.82	13.26	16.05	23.40	46.00
	Land footprint [ha]	4.3	5.4	6.6	8.0	11.7	23.0
	Energy capacity [MWh]	11.1	18.2	29.5	44.2	69.6	215.4
H ₂ tank	Volume capacity [m ³]	24.4	36.6	60.9	85.3	134.1	402.2
	Land footprint [m ²]	60	90	150	210	330	990
EL	P _{nom} [MW _{el}]	1.05	1.75	2.58	3.44	4.91	7.42
FC	P _{nom} [MW _{el}]	0.29	0.53	0.77	1.00	1.00	1.00

In terms of average annual cost of electricity provision, the results of the sensitivity analysis are shown in Fig. 3, compared with the costs obtained locating the same system in southern Italy (Ragusa). Indeed, the latitude affects the results because of the different solar radiation, leading to smaller annual hydrogen

storage need in southern areas. Therefore, for any imposed self-generation share the total average cost is lower in southern Italy, where the ‘best’ case self-generation increases to 38% (vs. 29% in northern Italy). In both locations, due to seasonal H₂ storage need, the cost increases faster when approaching 100% self-generation. However, electricity costs are quite different: while in the northern Italy case the price triples with respect to the reference case, in the southern case it only doubles.

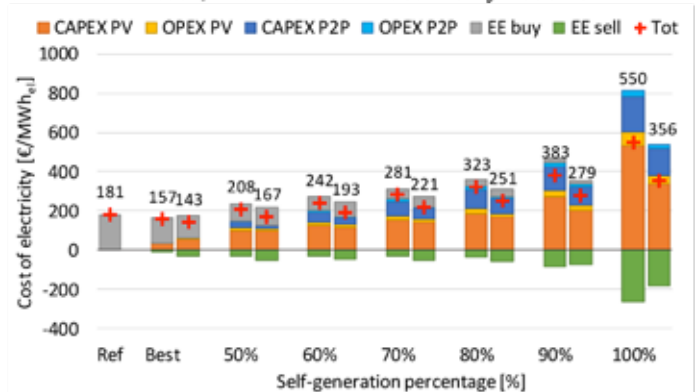


Fig. 3. Annual average cost of the electricity to the 1-MW load, in north Italy (left bars) or south Italy (right bars). Ref = only consumption from grid.

A further sensitivity analysis shows how the ‘best’ case solution for the plant in northern Italy conceptually varies with the cost of grid electricity. Increasing this cost up to very high (and unrealistic) prices, at 400 €/MWh_{el} more PV is installed, reaching 35% self-generation, but installing a P2P system becomes favorable only if this cost is increased further; only when the grid electricity price equals 800 €/MWh_{el}, the optimal solution (P2P included, 87% self-generation) almost halves the electricity provision cost with respect to buying all the electricity from the grid. A further increase in the cost would be needed, at present component costs, to make the 100% self-generation competitive.

V. CONCLUSIONS

With the present cost of grid electricity and today’s investment cost of P2P components, the economic viability of installing a P2P system strongly depends upon the available solar radiation. Anyway, a storage system is necessary when a high share of self-generation is desired and P2P allows to comply with the seasonal storage needs. Results show that up to 50-60% of annual demand coverage the PV+P2P system may guarantee a final cost of electricity below 170-240 €/MWh, depending on the location, while at higher shares the system would require further reductions in component costs to become competitive.

REFERENCES

- [1] Multi-Annual Work Plan 2014-2020, Fuel Cells and Hydrogen Joint Undertaking (FCH JU)