Master Thesis Project, 2022-2023

— Design and optimization of a hybrid PV/Thermal coupled system for effective solar water heating and electricity production —

Supervisor: Benoit DURILLON (L2EP - JUNIA, Lille) & Samer ALI (LGCgE – Junia, Lille)

Context

Perhaps the most popular application of solar systems is for domestic water heating. The popularity of these systems is based on the fact that relatively simple systems are involved, and solar water-heating systems are generally viable. The main part of a solar water heater is the solar collector array, which absorbs solar radiation and converts it to heat. This heat is then absorbed by a heat transfer fluid (water, non-freezing liquid, or air) that passes through the collector. This heat can then be stored or used directly. The amount of hot water produced by a solar water heater depends on the type and size of the system, the amount of sunshine available at the site, and the seasonal hot water demand pattern [1].

Apart from supplying hot water demands, generating electricity using renewable energy sources is another important task to be accomplished for a residential building. One of the green methods used to generate significant electric power is the PV generation using solar cells. These devices produce electricity directly from electromagnetic radiation, especially light, without any moving parts. PV panels can be used to provide hot water by dissipating electrical energy in multiple electric resistive heating elements [2]. Unlike other residential photovoltaic systems, the photovoltaic solar water heating system does not require an inverter to convert the direct current supplied by the photovoltaic array to an alternating current or a battery system for storage.

Comparing PV panels to solar water heaters for providing hot water, solar water heaters use sunlight more efficiently than photovoltaic systems, partly because of the complex series of interactions that happen in the photovoltaic panel. In addition, the silicon used in photovoltaic systems can't use as many wavelengths of light as the water heater, so some light goes to waste. Solar thermal systems convert 60 percent to 70 percent of the sun's energy into heat [3], while high-end photovoltaics top out at around 24 percent efficiency [4].

Photovoltaic systems, on the other hand, don't waste surplus energy. Electricity demand peaks at different times depending on the time of year and local weather. But, for the most part, we put the most stress on the grid when the sun is up and producing kilowatt hours, especially in the summer months. And even if roof panels produce more energy than you can use, the surplus feeds back into the grid, displacing energy that would have been produced by coal, gas, or nuclear plants. In other words, a rooftop photovoltaic system can spread its benefit across the entire energy grid. Solar water heaters help only a single household.

Another critical interest for a local use of solar energy is to enable the consumers to provide flexibility to the distribution grid [5]. Indeed, electrical grid are traditionally demand driven (the energy production is required to follow the energy consumption), but the smart grids offer nowadays new possibilities for the energy management of electricity and consumers may provide services to the grid operator, the main one being flexibility : the ability to lower, increase, or shift part of their consumption throughout the day or the week, depending on their interests (lowering the bill, their environmental impact, or helping their community).

The use of PV system coupled with thermal storage enables a better efficiency of the electricity produced and decrease the need of using a battery, a costly and more complex solution to implement [6]. Since heat can be directly drown from the solar irradiation through solar water heater, the question arises as to why not coupling PV system with solar water heaters to increase the flexibility based on the use of hot water cylinders inside residential dwellings.

Increasing the flexibility of residential prosumer especially is indeed one of the critical challenges regarding demand side management due to their complexity. However, they represent an important source of opportunities and the potential provision of flexibility by locally distributed energy resources is a hot investigation topic as shown and proved to be cost-effective in [7]. The question asked in this project is therefore: is there an opportunity using both electrical and thermal output of solar radiation in the daily flexibility of an household instead of the sole PV system?

Objective

Based on the above, this research subject involves the coupling of two systems (PV/Thermal solar water heater) to achieve an optimized co-generation system for both hot water supply and electric generation. The first objective is to provide an optimal arrangement for both systems for a given residential rooftop area with the idea to meet the annual hot water and electric users demands. Once this model achieved, and PV panel being already widely considered for electricity flexibility, the final objective is to provide an electric flexibility study of coupled PV/thermal solution compared to PV only. Moreover, the coupled system will be analyzed based on its energetic performance, environmental impact, and financial payback period.

Work Packages

WP1 [M1-M2]:
1-Perform a literature review about solar water heating systems types, solar collector types, thermal storage systems and residential flexibility (related to residential thermal storage systems).
WP2 [M2-M4]:
2-Define the problem that will be used for the analysis: the rooftop area, geographical location, building orientation, hot water, electrical needs, and grid flexibility requirement.
3-Gather information related to weather conditions and solar insolation for the chosen location along the year, as well as the residential consumption used to define flexibility.
4-Develop a mathematical model to accurately predict the electrical power output, outlet hot water temperature in function of various parameters: solar insolation, ratio of PV to Thermal collector areas, water mass flow rate, inlet water temperature, series vs parallel solar thermal collector connections, etc.
WP3 [M4-M5]:
5- Perform a parametric study by varying the different input parameters and analyse the effect on the outlet hot water temperature and electrical power output. Moreover, compare the performance of different types of solar collectors: flat plate, solar trough, evacuated tube, etc.
6- From the electrical grid point of view, compare the flexibility offered by the coupled system with a system using only PV.
7- Perform an economical study and calculate the financial payback period for each design.
WP4 [M5-M6]:
8- Write a report based on the above results.

Key word

PV Panels, Solar Water Heating, Solar Collectors, Energy Efficiency, Distribution Grid Flexibility, ….

References

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