Study and optimisation of hybrid photovoltaic thermal collectors and integration in small-scale prosumer energy systems

In the current global context of pollution, depletion of resources and climate change, the development of renewable energy technologies is crucial. Solar energy is among the most abundant and most promising energy sources, with high potential for sustainable development. The two conventional technologies for converting solar energy intro useful energy are photovoltaic and solar thermal collectors. To improve the market competitiveness and to increase the conversion rate of solar energy into useful energy, photovoltaic-thermal (PVT) panels have been developed. These are hybrid equipments that incorporate the two conventional technologies (solar and thermal panels), generating simultaneously both electricity and heat in a micro-cogeneration equipment. PVT systems are in particular beneficial in locations where space is limited, such as urban areas, as they increase the rate of conversion of solar energy per square meter. Moreover, the conversion of thermal energy leads to the cooling of the system which brings an additional advantage of increasing the efficiency of the photovoltaic cells, as they are impacted negatively by overheating.

A hybrid photovoltaic thermal (PVT) collector is a module in which the photovoltaic (PV) layer is not only producing electricity but also serves as a thermal absorber. As a result, power and heat are produced simultaneously. The performance of a hybrid photovoltaic thermal collector is dependent on multiple parameters: climate conditions, thermo-physical, geometrical and electrical properties. In this research, a dynamic numerical model is proposed to simulate the heat exchange in the layers of the PVT panel. The model consists of a system of simultaneous equations solved in MATLab, and it can evaluate the temperature in each of the layers of the collector at any given time. The model was applied to two different climatic conditions: Bucharest, Romania and Strasbourg, France, in order to assess and compare their behaviour. The results show the temperature of each layer at any particular time, and a slightly higher temperature of the working fluid can be observed in Bucharest during the summer, and in Strasbourg during the winter. The model is validated and can be applied to any climatic conditions and adapted for any geometrical or thermo-physical configuration. Next, a one-factor-at-a-time parametric analysis is carried out in order to assess the impact of various parameters on the electrical, thermal and global efficiency. Based on this analysis, a number of technical recommendations have been proposed.

A transient simulation of a small sized domestic household system was carried out in TRNSYS, comparing the system performance in Bucharest and Strasbourg. The results indicated a slightly better yearly performance in Bucharest. Overall, the yearly energy production of electricity and heat, both supported by back-up solutions (auxiliary heater and battery bank respectively) indicates that the energy demand of an average single family house could be covered to about 50\% over one year, with a slightly better performance in the Bucharest climate compared to Strasbourg. This was expected due to the slightly better meteorological conditions.

In all co-generation systems there is an equilibrium that needs to be achieved between the produced heat and power. Thus, establishing the inter-connection and relationship between the two is important. This research investigated the impact of the variation of a number of thermal parameters on the electrical output of a PVT collector. An OFAT analysis is performed for the following parameters: tank outlet flow, tank size, consumer demand curve and the temperature of the cold water main. The analysis is done on a transient simulation of a PVT system modelled in TRNSYS. The most significant impact on the electrical efficiency (6.8\%) is caused by variation of the flow rate to the consumer. The size of the tank has an impact of 4.7\%. Also, it was noted that the peak electrical efficiency is simultaneous with the peak consumer demand, thus matching the demand curve with the production curve is also an important aspect. Another aspect investigated in this section is the instantaneous variation of the electrical and thermal power of the system as a function of the PVT inlet temperature.

An experimental study of a demo system from the UPB campus was carried out. The daily analysis of four representative days (spring cloudy day, spring clear day, summer cloudy day, summer clear day) showed that the best thermal performance of the system occurs on the warm clear days, while the best electrical performance occurs during the colder cloudy days, and generally there is a tradeoff between the electrical and thermal performance. When comparing PV and PVT collectors, it was concluded that PVT per- forms better in the days when there is no excess of heat accumulation in the tank; on the other hand, the PV performs slightly better during the days when the tank thermal energy is not dissipated. As a technical recommendation, PVT collectors are only appropriate in systems that have a nearby source of heat dissipation, either to a consumer or in thermal storage.

The economic overview of the PVT market and the available subsidies revealed the fact that there is still a lack of standardisation at a European level, and lack of clarity regarding the classification of PVT collectors in the solar energy technologies. In terms of economical evaluation, subsidies are an important parameter for establishing the benefits of the investment. Three scenarios were investigated, with high, medium and no subsidy, and the results showed a payback period of the investment between 7 and 15 years, which is comparable to the traditional solar technologies.

Overall, small scale PVT technology appears to be a promising solution for maximum solar energy conversion, with some significant benefits over the standard PV and thermal collectors, especially in the residential and urban sectors. Additional demonstrative projects, consumer awareness, standardisation and proof of concept are required to push this technology further on the mainstream market.