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New microcogeneration with solar energy: stirling, thermal and photovoltaic systems

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Abstract.

This paper analyses the viability of a new microcogeneration system with a Stirling engine-based micro-CHP (combined heat and power) and renewable solar energy: thermal and photovoltaic system in order to supply the energy demand of an isolated home. The right sizing of solar energy systems should allow optimizing both the available solar resources and gas consumption for one specific climatological conditions.

The present work shows the first results of the experimental study of a micro-cogeneration system (micro-CHP based on the Stirling motor) supported with renewable energy. The system of self-government covers the theoretical daily consumption of a house.

In this results, the different contributions of the subsystems to the daily thermal and electric demand are displayed.

Key words

Microcogeneration, stirling engine, solar energy, photovoltaic system.

1. Introduction

Nowadays sustainable energy policies are reducing energy consumption in buildings and producing the required energy in a more efficient way than few years ago. Moreover, the reduction of costs of solar energy systems, especially significant in photovoltaic systems, allow cost effective alternatives to conventional energy systems.

There are technologies such as micro-cogeneration which have been improving during the last years, since it works with many functional and economic advantages over the conventional kinds of production.

Stirling engine based micro-CHP devices have been analysed during last years and are becoming a solution for supplying heating, domestic hot water (DHW) and electrical power such as I. González-Pino et al. concluded [1,2]. Valenti and Silva [3] compared the alone micro-CHP unit in an experimental and numerical analyses of the device. Improving the performance of a micro-CHP device is related with keeping a constant heat demand since when electricity is produced you can take advantage of the heat that is also being produced [4] and that is why "District Heating" is a trend as studied by Emmanouil Malliotakis et al. [5]. In application to energy production, Karmacharya and Putrus [6] go further in a simulation with multiple micro-generators: a micro-CHP device supported with a wind turbine and a photovoltaic panel.

The proposal system has stirling engine like novelty in cogeneration systems combined with renewable energy. Without this engine, there are many studies about cogeneration. "Trigeneration for domestic purposes in isolated areas based on hybrid RES" L. Acevedo et al. [7] is an analysis about this systems published in International Conference on Renewable Energies and Power Quality (ICREPQ'17). With focus in rural applications Jan Iwaszkiewicz et al. published " A practical approach to the cogeneration system for rural appliances" [8]. Similar focus tan this work has the article "Design and operation of a local cogeneration plant supplying a multi-family house" published by M. Fernandez et al. [9] in this case for 9.5 kW electrical and 35 kW thermic power. Cogeneration system with thermal engine and photovoltaic was analysed by M. Dondas [10] in Fuel consumption minimization of a cogeneration system multi machines associated with a photovoltaic

2. Experimental facilities

The laboratory of cogeneration in Málaga University (Fig. 1, 2) has three systems for energy production and storage system.

Fig. 1. Laboratory of Cogeneration.

The micro-cogeneration consists of a Whispergen EU1 Stirling micro-CHP unit. A solar thermal system with two solar collectors and one 300 L associated storage tank. The solar collectors are installed in a parallel circuit to the Stirling hot water production. One photovoltaic systems of 3.0 kWp peak power with an electrical storage of 48V lithium-ion battery and 10 kWh of capacity. The entire electrical system is controlled by a photovoltaic inverter Sun Storage 1play 3TL. The electrical part of the micro-CHP unit is also connected to the inverter.

Fig.2. View of the Photovoltaic modules and thermal collectors

It is also able to connect to the grid and has the Stirling as auxiliary electric source.

The technical characteristics of the systems are summarized in table 1.

A weather station measures real time data of the solar irradiation, ambient temperature, humidity, wind speed and direction as well as the photovoltaic module temperature.

A control system based in a PLC Mitsubishi model L02CPU-P with an interface GT2510-VTBA commands the whole system and manages the production and the activation of the loads according to a provided flowchart, this allows simulate any demand profile in electrical or thermal energy. The operating data of all the systems in real time are recorded. In Fig.3 the diagram of the experimental system is shown.

Table 1. Technical characteristics of the system

Stirling micro-CHP	
Model	Whispergen EU1
Engine	4 Cylinders double acting Stirling cycle
Electrical output	Up to 1 kW
Thermal output	Up to 7 kW
Fuel consumption	1.55 m^3/h
Solar thermal system	
Collector model	Chromagen
Collector area	3.54 m^2
Recommended flow	45 l/h· m^2
Maximum pressure	10 bar
Storage tank capacity	300 l
Electronic DC/AC control	
Inverter model	Ingeteam Sun Storage 1play 3TL
Storage system connection	
Voltage rank	48-300 V
Maximum charge/discharge	50 A
Photovoltaic connection	
Voltage rank	300-450 V
Maximum intensity	20 A
Consumption connection	
Maximum permanent power	3000 W
Maximum intensity	13 A
Performance	
Maximum efficiency	95.5 %
Euroefficiency	95 %
Accumulation system	
Battery Model	LG Chem Resu 10 Li-Io
Nominal Voltage	51.8 V
Voltage Range	42.0-58.8 V
Usable Energy	8.8 kWh
Capacity	189 Ah
Photovoltaic system	
Nominal peak power	3000 Wp
Nominal power of the modules	245 Wp
Module efficiency	15.04 %
Intensity of maximum power	8.33 A
Voltage of maximum power	29.37 V

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The system works according to an established flowchart. This flowchart allows optimizing the use of renewable sources and save gas consumption. In this way, the micro-CHP is an auxiliary source for both thermal and photovoltaic system.

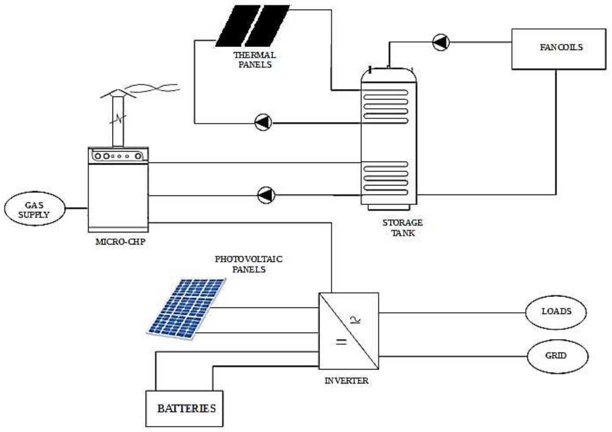


Fig.3 Diagram of the experimental system

3. Result and discussion

This work shows the results of the operation of the system described above for a sunny day (10/26/17) with an average daily temperature of 18.7 ºC and a daily irradiance of 6.7 kWh/m^2.

Fig. 4 shows the theoretical and experimental hourly electricity consumption. By theoretical consumption, it indicates the consumption programmed in the system and the experimental consumption is the real consumption of the system on this day. A good agreement between both represented values is observed. The daily electricity demand was 17.5 kWh.

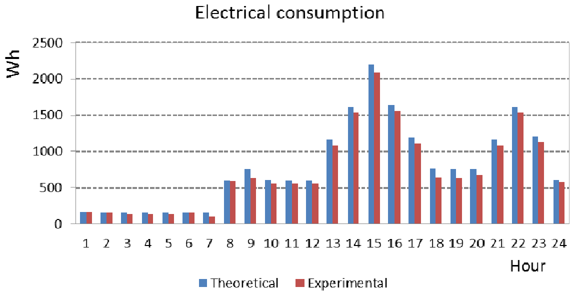


Fig.4. Daily electrical load profile

Fig.5 shows the daily electrical energy balance of the system. As can be observed, during sunny hours the consumption is covered directly by the photovoltaic system. If the PV production is greater than the consumption, the remaining energy charges the batteries and discharges them in the opposite case. When the battery reaches its maximum state of charge, the inverter regulates the point of maximum power of the photovoltaic generator to adapt the production to the required consumption (from 12:00 to 17:00 in this case). According to the irradiation received, the expected photovoltaic output was 15.9 kWh. However, the daily production has been only 11.1 kWh. This means that 30% of the solar resource has not been exploited.

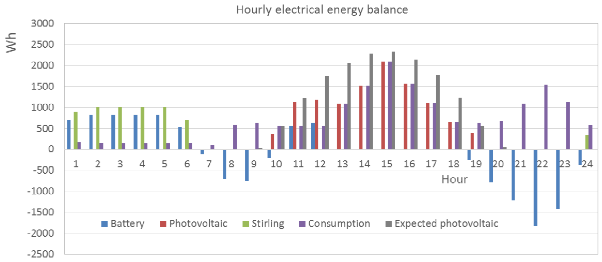


Fig. 5. Hourly electrical energy balance.

On the other hand, if the battery reaches its minimum state of charge and the photovoltaic system is not able to meet the demand, then the micro-CHP is started (from 23:00 to 6:00). In this case, the micro-CHP supplies electrical energy to the system until the battery reaches a state of charge of 80%, and also produce corresponding thermal energy. The micro-CHP will then cease its production if the hot water demand is also satisfied. Negative battery values mean that the battery is being discharged and positive ones represent the charge.

Table II. Daily electrical energy balance

	To consumption	To Battery
Photovoltaic	89 %	11 %
Stirling	21 %	79 %
	Consumption	
Photovoltaic	Stirling	Battery
53 %	6 %	41 %

Table II summarizes the daily energy flows of the system. As the table also shows, the photovoltaic system has directly covered 53% of the consumption, while the Stirling has been used mainly to charge the battery. This system has only directly supplied 6% of the consumption. The photovoltaic energy supplied directly to the load has been 89%.

According to the diagram of figure 3, all the thermal energy produced by both systems is accumulated in the thermal reservoir. In this way, the micro-CHP starts when the solar panels are not able to cover the thermal demand. If the temperature of the thermal tank reaches its maximum value and the micro-CHP is on, for electric necessities, the fan coils start to dissipate thermal energy independently of the established thermal consumption profile. As consequence, the programmed and experimental thermal demand curve present important discrepancies as can be seen in Fig.6. However, daily consumption has been lower than expected. The scheduled daily thermal consumption was 57 kWh while the system has supplied 52 kWh. This happens due to a protection that restricts thermal consumption when the thermal reservoir is under 30ºC, in order to provide user´s comfort.

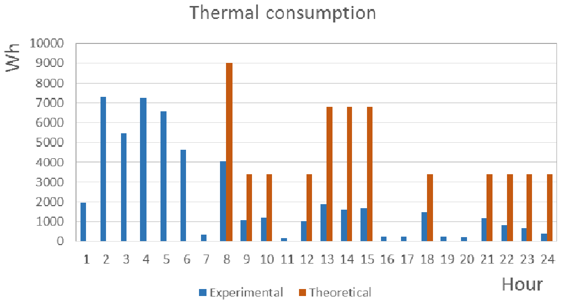


Fig.6. Daily thermal load profile

Table III. Daily thermal energy balance

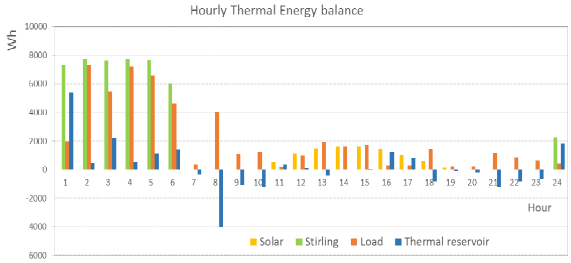
Generated	
Collectors	17 %
Stirling	83 %
Use	
Consumption	92 %
Accumulation	8 %

Fig.7 shows the daily thermal energy balance of the system, where it can be seen that the contribution of the thermal collectors is far less relevant as the Stirling unit (17% of the first versus 83% of the second from the total generated energy, see Table III). Of this generated energy, the 92% has been used to supply the thermal loads and the remaining 8% has been accumulated (see Table III). As it has been mentioned before, the total thermal consumption is greater than the generation. Thus, the temperature of the thermal reservoir logically decreases from 38,05 ºC at the beginning of the day to 32,02 ºC at the end.

4. Conclusions

In this paper first operating data of a new microcogeneration system have been analysed. The study also shows the compatibility between these systems: Stirling engine-based micro-CHP (combined heat and power) and renewable solar energy: thermal and photovoltaic system to supply the energy demand of an isolated home

The results displayed show that it is possible to cover the energy demand of a house with these combined energy systems. However, only more detailed operation system study in different climatic conditions will be achievable to determine the solar systems´ optimal size, in order to maximize their use and thus minimize gas consumption. The results show that while the size of the photovoltaic system seems adequate, for this demand profile, directly covering 53% of the electricity consumption. The solar thermal system should be increased due to it only covers 17% of the consumption. Furthermore, in both cases the strategy implemented does not allow the maximum use of the solar resource, but it rice a high level of optimization.



The main role of the storage's proper sizing (thermal and electrical) has been stated in order to achieve optimization in the system's operation.

Fig.7. Hourly thermal energy balance.

These results show the complexity of jointly controlling the different systems to satisfy the energy demand in isolated system.

Acknowledgement

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