Hydrogen-based energy storage for a distributed generation system

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Introduction

One of the most typical distributed generation systems are electrical microgrid, which consist on small electrical grids, generally connected to the main grid, with a decentralized management structure. Electrical microgrids allow higher renewable energy integration in the grid, achieving a cost decrease and improving the grid quality [1]. These microgrids incorporate renewable generation systems and energy consumers. Moreover, they have storage systems to balance generation and consumption as well as the exchanged power with the main grid. Traditionally, lead-acid batteries have been used in microgrids. However, these batteries have some drawbacks, being the most important its poor performance in partial state of charge, which is critical for a microgrid. A suitable option for the storage system is hydrogen technology. These systems have high energy density, which makes the storage system able to assume seasonal variability of renewable resources [2, 3].

This paper proposes a sizing methodology for storage systems based on hydrogen for grid-tied electrical microgrids. This methodology optimizes the relationship between the storage system size and the consumption of grid power.

Description of the electrical microgrid

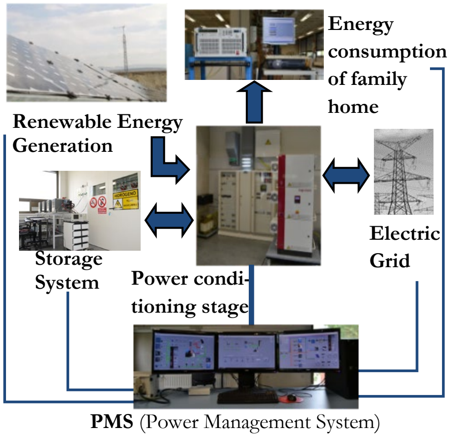

Figure 1. Scheme of electrical microgrid.

The electrical microgrid, located in the Renewable Energy laboratory at Public University of Navarre, has a photovoltaic–wind hybrid renewable generation system, as can be seen in the schematic shown in Figure 1. The photovoltaic generator has a peak power of 4 kW and the wind turbine rated power is 6 kW. The storage system comprises a water electrolyser (WE), a pressurized hydrogen tank and a fuel cell (FC). A PEM FC is chosen because of its low operation temperature, its fast start up and its rapid response to load variations. An alkaline WE is used since its cost is lower than PEM type while the hydrogen purity is enough for the FC operation. The power conditioning stages are integrated in a hybrid power converter. Moreover, there is a power management system (PMS) for the measurement and control of microgrid energy flows in real time. The measured variables are stored in a database with a one-second sampling rate. The microgrid consumption is emulated by programmable electronic load based on real consumption data measured in a near-by family home with a subscribed power of 3.3 kW and an annual consumption of 3234 kWh.

Sizing of the hydrogen-based storage system

Firstly, an analysis of generation and consumption data is performed in order to size the hydrogen-based storage system for the electrical microgrid. The input data are electrical power, both generated and consumed, measured in the electrical microgrid in the course of a year, from 1st August 2013 to 31st July 2014. The power assumed by the storage system and the grid (P_{NET}) is calculated by the difference between consumption and generation. Then, high-pass filters with different cut-off frequencies are applied to this power. Each filtered power will be managed by the hydrogen-based storage system (P_H), whilst the difference between P_{NET} and each P_H corresponds to the power covered by the grid (P_G). Furthermore, in line with new self-consumption laws promulgated in some countries, which penalize the power injection into the grid, the grid is only used for power consumption ($P_G>0$). Furthermore, the WE power is limited to 3 kW in order to reduce the hydrogen-based storage system cost. Therefore, not all the generated energy is stored, but only the needed to cover the consumption. Each cut-off frequency defines the operating interval of the storage system and determines its size. In other words, the hydrogen-based storage system manages the power above each cut-off frequency, while the grid is used to provide lower frequencies. The filter time constant ranges between 12 hours and 15 days (360 hours). Once P_H and P_G are obtained for each time constant, the stored energy in the hydrogen system (E_H) and the consumption from the grid (E_G) are figured out.

From the sizing of hydrogen tank, the storage system charge or discharge efficiency is taken into account studying the FC and WE. When P_H is positive, E_H is multiplied by the inverse of the discharge efficiency $1/\eta_d$. This is due to the fact that, in order for the storage system to provide this energy, the system has to store the discharging-process losses. Likewise, when P_H is negative, E_H is multiplied by the charging performance, that is η_c, given the fact that the stored energy is lower than the energy fed into system. The maximum value of E_H is the maximum energy stored into the tank in the course of the year (E_{TH}). A mean overall efficiency of $\eta c=0.65$ was adopted for the WE based on the hydrogen LHV (3000 Wh Nm^{-3}) [3]. Regarding the discharging efficiency, corresponding to the FC, a mean efficiency of $\eta_d=0.5$ is used also based on the hydrogen LHV [4].

Figure 2a compares E_{TH} with the annual energy supplied by the grid (E_{TG}) for each high-pass filter time constant (in hours). The E_{TH} bend is a good trade-off among E_{TH} and E_{TG}, which gives a time-constant range between 24 and 96 hours. The final selection is 48 hours, which corresponds to a hydrogen stored energy of E_{TH}=368 kWh. In turn, the energy supplied by the grid during a year is E_{TG}=354 kWh. E_{TG} represents less than 10% of the annual energy consumed by the home. The evolution of the stored energy in the hydrogen tank for a complete year of the microgrid operation with the adopted solution is shown in Figure 2b. It can be seen that the stored energy decreases during winter since the generated power is lower than consumption. An increase in this stored energy is appreciated during spring and finally, in July, the tank is completely full. Consequently, this tank size makes the storage system able to cover the seasonal variations of renewable resources. Figure 2c shows P_{NET}, P_H and P_G for the same year. The operation of the FC takes place when P_H is positive, whilst WE works when P_H is negative. Likewise, P_G is always positive because of the no grid injection criteria. It can be seen that P_G has not important variations and a maximum value of 0.34 kW. Consequently, the subscribed power can be reduced by a 90% with respect to the initial rate. Moreover, it can be seen that P_H is the difference between P_{NET} and P_G, with the exception of the situations when the WE maximum power is reached. To sum up, the hydrogen-based storage system requires a FC and a WE, both with a rated power of 3 kW and a 368 kWh hydrogen tank to be able to manage the home power consumption with the help of the grid.

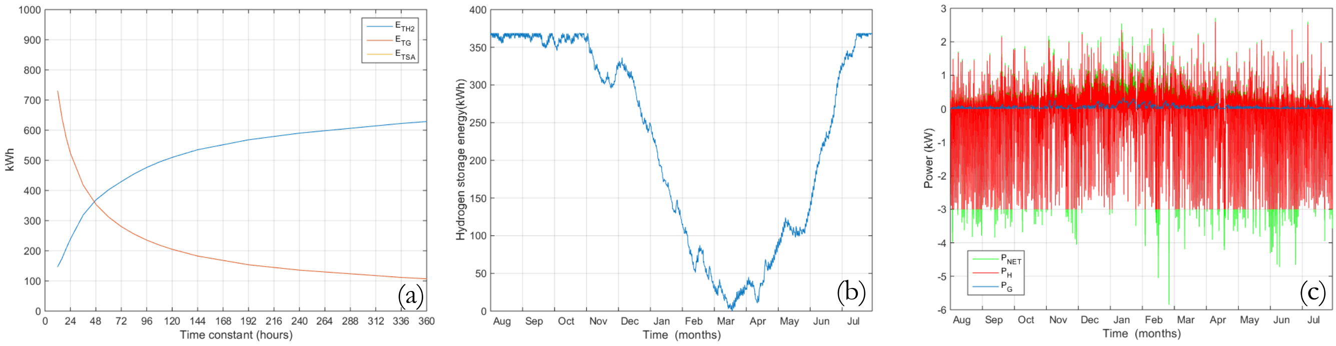

Figure 2. a) Required energy of hydrogen tank (E_{TH}) and annual energy supplied by the grid (E_{TG}) for each high-pass filter time constant. b) Evolution of the stored energy in the hydrogen tank for a complete year. c) Net power (P_{NET}), hydrogen power (P_H) and grid power (P_G) for a high-pass filter time constant of 48 hours for a complete year.

Conclusion

A sizing methodology for hydrogen energy storage systems for an experimental grid-tied microgrid has been proposed. This methodology results in a feasible storage system which is complemented by the grid. Two main advantages are associated with the proposed energy storage system. On the one hand, the grid energy is as low as 10% of the annual consumption. On the other hand, grid power has only slow variations and the subscribed power can be reduced approximately by 90%.

Acknowledgements

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