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Sizing criteria of hybrid photovoltaic–wind systems with battery storage and self-consumption considering interaction with the grid

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Abstract

The aim of this paper is to analyze the influence of some sizing parameters of grid-connected, hybrid wind-photovoltaic systems provided with energy storage and load consumption, on their interaction with the electrical network. These sizing parameters are the sizing factor (defined as the ratio between the yearly energy produced by the renewable generation system and the yearly energy demanded by a consumer), the solar and wind fractions, and the size of the batteries. The analyzed case study is the supply of energy to a typical residential load in Spain. Annual hourly-based series of energy production from wind and photovoltaic installations in operation in Aragon (an eastern region of Spain) are used as data inputs to a Matlab model of the system. Yearly energy balances for hybrid systems with different combinations and sizes of photovoltaic (PV) plant and wind energy conversion system (WECS) plus Battery Storage Systems (BES) are simulated in an hourly basis. These hybrid systems can inject or absorb energy from the grid depending on whether the energy produced is higher or lower than the household consumption and their operational limits are not exceeded. The interaction with the grid is evaluated in terms of energy injected in or absorbed from the grid, electrical (Joule) losses in lines and load duration curves (LDCs). Although the problem is case-dependent and the correct sizing of such systems is only possible with the knowledge of generation and consumption profiles, some general criteria can be extracted from the results of this paper. Conclusions are also valid for pure PV or Wind systems.

Keywords: Hybrid systems; Photovoltaic and wind energy; Energy losses; Battery energy storage; Grid connection

1. Introduction

One of the challenges in the near future is to obtain enough clean energy supply that helps to contain global warming effects, to reduce the fossil fuel dependence and to avoid the economic impact from raising oil prices. The use of renewable energy sources (RES) is one of the best ways to ensure that human energy needs are satisfied while solving the previously mentioned problems. Wind energy conversion systems (WECS) and Photovoltaic (PV) systems are called to play a fundamental role in the embedded generation of electricity. They can be used in stand-alone

Abbreviations: AEA, Annual Energy Absorption; AEI, Annual Energy Injection; BES, Battery Storage Systems; DOD, Depth of Discharge; FIT, Feed in Tariff; GLF, generalized load factor; LDC, load duration curve; NLDC, Net Load Duration Curve; PV, Photovoltaics; RCL, Ratio of Conductor Losses; RES, renewable energy sources; SOC, State-of-Charge; WECS, wind energy conversion system.

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applications or connected to the grid, usually in distribution networks, providing energy near the point of use, reducing losses in transmission and distribution systems. Emission of greenhouse gases associated to other polluting generation units are avoided as well. Reduction of peak grid demand by grid-connected RES systems is also interesting from a utility's point of view. Many governments such as Germany, Italy, Spain and France, recognize the advantages of RES installations in buildings, providing a favorable legislation with incentives for integrated solutions to compensate the higher upfront cost (Colmenar-Santos et al., 2012; Mulder et al., 2010). New legal regulations for small RES installations encourage consumers to maximize self-consumption by offering better tariffs.

However, the integration of renewable energy generation leads to major challenges for distribution grid operators (Beaudin et al., 2010; Hemdan and Kurrat, 2011; Nykamp et al., 2012; Pecas Lopes et al., 2007). The outputs of the PV and wind generation are not constant and vary with the hour and season. Demand is also largely uncontrollable and variable (Borowy and Salameh, 1994). Wind power and photovoltaic generation can complement each other and some problems caused by their variable nature can be partially overcome by integrating these two energy resources in a proper combination, improving the system efficiency and reliability (Zhou et al., 2010). When an energy system includes two or more energy sources is named hybrid. The use of two different resources together increases the complexity of the system in comparison with single energy systems and makes the hybrid systems more difficult to analyze (Borowy and Salameh, 1996; Celik, 2002).

The problem of variable and unpredictable supply from renewable sources could be solved with the development of good energy-storage systems (Diaf et al., 2007; Kim et al., 2008; Mulder et al., 2010). There are a number of studies about the optimization and sizing of Wind/PV hybrid systems in stand-alone applications (Ai et al., 2003; Bagul et al., 1996; Bakos and Tsagas, 2003; Beyer and Langer, 1996; Celik, 2002, 2003; Diaf et al., 2007, 2008; Eke et al., 2005; Ekren et al., 2009; Hocaoglu et al., 2009; Kaabeche et al., 2011; Kellogg et al., 1996; Luna-Rubio et al., 2012; Markvart, 1996; Morgan et al., 1997; Muselli et al., 1999; Prasad and Natarajan, 2006; Protogeropoulos et al., 1997; Seeling-Hochmuth, 1997; Yang et al., 2007, 2008a,b; Zhou et al., 2010). But there are few studies of grid connected hybrid energy systems. These systems are suitable in self-consumption systems where the main priority of the system is to cater the local energy demand and occasionally to feed the grid with any energy surplus (Kaundinya et al., 2009; Luna-Rubio et al., 2012).

The capacity of the storage device for the systems connected to the grid can be smaller than those designed for stand-alone applications since the grid can be used as a system backup. Energy storage can be a valuable resource for the power system by maximizing the efficient use of renewable energy resources, adding flexibility to electric utilities. It presents a very important strategic value in future electricity networks: by storing the power from renewable sources during off-peak periods and releasing it at on-peak times, coincident with periods of peak consumer demand, energy storage can transform this low-value, unscheduled power into a schedulable high-value product. The stored energy can be re-exported provided there are no voltage constraints, and it can thus be used to take advantage of fluctuating electricity market prices. By shifting load from peak to off-peak periods, generation cost could be reduced and the utilization of investment improved. The procedure of charging at the off-peak-time and discharging at the load-peak-time is called 'Load Leveling' (Wagner, 1997). On the other hand, it is desirable to shave peak demand in order to defer generation, transmission and distribution equipment upgrades, and reduce or avoid the need to purchase much higher cost generation assets. When peak power (kW) limits are placed in the electricity contract, the electricity bill is reduced by 'shaving' the peaks. Moreover, the electrical losses in the power system are a function of the generation and consumption patterns. Storage could be used to reduce peak flows through cables and transformers, relieving overloaded network components (capacity release and reduction of losses) and enable an increase level of distributed generation to be connected to the existing distribution network.

Energy management strategies have to be developed, in conjunction with a communication path for dispatching, to allow the grid operator to define its special needs depending on the grid situation (Castillo-Cagigal et al., 2011a,b). In the relatively slow process of transition towards real active smart grids, (mainly due to inertia and reluctances of the electrical companies and economic costs), it would be an interesting aim to maximize the renewable energy penetration but minimizing the interaction with the grid. Hence, it is very important to analyze the effect of the size of the generation units and the capacity of the batteries on this interaction with the grid, the peak power injected or absorbed, the electrical losses and the load factors.

This paper presents an analysis of the interaction of hybrid PV-Wind systems plus batteries with the grid, and the study of the best combination of these RES and the size of the battery. The cases of pure PV and pure WECS (plus storage) are also shown. The aim of the paper is to analyze how the hybrid composition of the renewable generator (solar and wind fractions), the sizing factor (defined as the ratio between the yearly energy produced by the RES generator and the yearly energy demanded by a consumer) and the size of the batteries affect the amount of energy injected or absorbed from the grid. For this purpose, a Matlab model of the system has been developed and annual hourly-based series of energy production from real wind and photovoltaic installations have been used as data inputs to the model. The scenery of demand considered has been estimated from the REE (*Red Eléctrica de España*, the sole transmission agent and operator of the Spanish electricity system) hourly summer and winter standard days.