Journal of Energy Storage 17 (2018) 287–298

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

Residential micro-grid load management through artificial neural networks

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ARTICLE INFO

Keywords:
Load management
Residential micro-grid
Battery
ANN

ABSTRACT

This paper presents an innovative load management tool for a micro-grid composed by a photovoltaic (PV) system and an energy storage device installed at a residential user.

The objective is to develop a suitable residential load management to maximize the PV plant exploitation through the storage system in order to achieve a greater energy independence of the micro-grid (MG) from the electric grid. For this purpose a MG dynamic model was developed in Matlab Simulink environment useful to analyse and optimize the MG energy performance.

On the modelling results, through artificial neural networks (ANN) technique, a hierarchy load management that takes into account of the load demand, battery state of charge and weather forecast was defined. Specifically the aim of the ANN model here proposed is to predict the scheduling of programmable loads considering the weather conditions relative to the current day and the previous one, beyond that on the weather forecast for the day after. The obtained results, considering the relatively small dataset, are to be considered strongly encouraging. Greater performance is expected in the case the data set is enlarged.

1. Introduction

Nowadays, the substantial increase in Renewable Energy Sources (RES) exploitation makes necessary to control and regulate the events of renewable energy over-production or sub-production [1,2]. RES are non-programmable sources because of their intermittent and fluctuating intrinsic character [3] (e.g. wind, solar energy). As consequence, globally, systems powered by non-programmable RES negatively affect grid safety and stability and force the thermal power plants, with particular reference to combined cycles fed by natural gas, to a continuous power up to compensate their variations and to avoid network imbalance [4–8].

Anyway the interest in this issue arises from the need to fully exploit the energy produced by non-programmable RES. Integration of RES electric production into the power grid, even at national level, is therefore a crucial and critical issue which requires research and development efforts to maximize the exploitation of these plants.

The way to achieve the effective management of fluctuations and intermittent behaviour of RES is based on the availability of smartly controlled intelligent networks and infrastructures, capable of managing power streams innovatively by optimizing the whole electric system.

To drastically reduce the RES variability and uncertainty, there are various possibilities. An efficient opportunity to synchronize RES working operation with electric grid can be the adoption of storage systems [9,10].

In [11–13] are shown overviews about the relevance of energy storage penetration in future power networks. Specifically, in [12,13] different energy storage technologies and their possible time-variable operation modes are analysed. Also in [14] several ways to store energy, with a range of more or less developed commercial and pilot technologies, are presented.

Summarizing, an Energy Storage Systems (ESS) can be used to store energy surplus, due to overproduction contextual to low power demand, and to allow its post-usage when required. So, specifically, the use of ESS can lead to the three following situations:

a) Storage makes possible the deferred use of the produced energy in the complete or partial absence of a concurrent energy demand.
b) Storage allows to the user to exploit power at a different power level than that at which it is available during production.
c) Storage system must be reversible (not in thermodynamic sense), i.e. it must allow the deferred use of almost all accumulated energy according to its energy efficiency.

In technical literature several studies propose various optimization tools for residential demand response (DR). Moreover, in the presence of PV plant, the batteries utilization to increase the exploitation of PV self-consumption and reduce the cost due to electricity withdraw are analysed [15–17]. In [16] an interesting comparison between batteries

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https://doi.org/10.1016/j.est.2018.03.011
Received 4 December 2017; Received in revised form 5 February 2018; Accepted 19 March 2018

and hydrogen storage performance is presented. It results that battery technology is more suitable than hydrogen to perform PV self-consumption thanks to higher round-trip efficiency and negligible self-discharge. In [18] an economic optimization, based on genetic algorithm, of a residential battery operation with a PV system is presented. The study concerns both PV self-consumption and demand-load shifting. Their results show that, for a household which already invested in a PV system, the addition of a battery storage is not yet economically viable due to tariff structure and battery capacity.

In literature, the topic of DR optimization is often dealt separately with respect to energy storage or RES production issues. Specifically, it is easy to identify research works in which the system optimization is aimed at minimizing costs due to network withdrawals rather than improving system efficiency or self-sufficiency. For example in [19], each residential load is classified into different categories according to different demand response capabilities in order to reduce the peak load and peak-valley difference. This optimization addressed to an electricity pricing strategy.

Furthermore, in [20,21] the residential loads curves are analysed and changed in order to ameliorate the DR, while [22] introduces a control strategy for all controllable loads in a single house based on TOU tariffs. In [23] a DR control model for heating, ventilating and air conditioning (HVAC) system of one house is developed. In [24] it is shown a scheduling model for shiftable loads of household. Also the thermal storage system is considered in DR model for single house in [25,26]. Several papers [27–32] are focused on Home Energy Management (HEM) modelling and formulations in order to reduce the energy cost for the customer as well as the household's peak load.

In [33–35] the priority for controllable appliances along with the associated thermal and operational constraints is set to determine which appliances can be turned off in the case of DR implementation. In [36] a Mixed Integer Linear Programming (MILP) is shown to plan and allocate residential load for consumption in order to conserve the user priority. In [37] the operation of a PV-battery backup system under intermittent grid electricity supply is optimized. In particular, Non-dominated Sorting Genetic Algorithm (NSGA-II) technique and a fuzzy-logic decision maker are applied to get closer to the users preferences. It was observed that the back-up installation size can be reduced. A Modified Mild Intrusive Genetic Algorithm (MMIGA) is applied for intelligent load management of PV powered residential building in [38]. For the optimization of the demand response genetic algorithms (GA) are utilized in [39,40], simulated annealing algorithm in [41], minimization and several multi-objective optimization techniques in [42].

As discussed above, in the literature there are numerous studies about DR optimization, characterized by different techniques aimed at minimizing the electricity purchasing cost. No research works characterized by a loads shift optimization, through neural network, are available. Moreover, a lack in the addressing the maximization of PV production exploitation at the same time as the optimization of storage system operation, in order to make MG as autonomous as possible from the grid, is observed.

In this context, the present study, according to an innovative approach, focused the attention on a residential micro-grid (residential user, PV plant, storage batteries) connected to the grid. Specifically, the purpose of this work was the development of a suitable loads management to realize, thanks also to the adopted storage integration, the maximization of the PV plant exploitation with a greater energy independence of the micro-grid (MG) in terms of:

- greater self-consumptions with respect to the PV production;
- lower electric consumptions with respect to the total energy demand.

Moreover, an artificial neural network (ANN) model was developed to estimate the daily programmable loads that can be turned on based on the determined control logic and the weather conditions over three days (the current day, the previous one and forecast for the day after). The study was performed according to the following steps:

- analysis of load profile and definition of a standard daily cycle of residential loads (i.e. home appliances);
- development, in the Matlab Simulink environment, of the MG dynamic model;
- development of a suitable load management strategy in function of the battery state of charge to optimize MG energy performance on daily basis;
- development of an upper hierarchy load management which, on the basis of the maximum number of standard load cycles per day according to irradiance level, allows to determine the proper loads sequence for the day (n), known the weather conditions for days (n) and (n − 1) together with the weather forecast for the day after (n + 1). Such a decisional procedure, developed by means of artificial neural networks technique, takes into account both seasonal and weather conditions effects.

2. Micro-grid layout

Fig. 1 shows an overview of the modelled system together with the considered power fluxes. It can be fundamentally divided into 3 areas: "Photovoltaic plant", "Battery storage system" and "Residential load".

As it can be noted, a bidirectional energy exchange was considered in input and output from battery and electric grid and, on the other hand, PV plant and residential load are respectively characterized by an output (RES production) and input (required load) power flux. All converters, with their efficiency and response delay, are not implemented in this dynamic model.

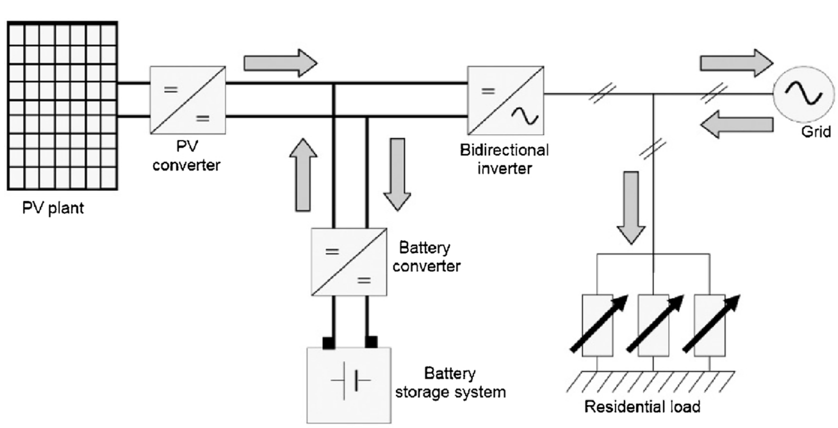

Fig. 1. Power direction in the modelled system.