Energy xxx (2015) 1–10

Contents lists available at ScienceDirect

Energy

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

Optimal electricity dispatch on isolated mini-grids using a demand response strategy for thermal storage backup with genetic algorithms

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ARTICLE INFO

Article history:
Received 28 June 2014
Received in revised form
14 January 2015
Accepted 17 January 2015
Available online xxx

Keywords:
Demand response
Thermal storage
Domestic hot water
Renewable energy
Genetic algorithms
Linear programming

ABSTRACT

The present study uses the DHW (domestic hot water) electric backup from solar thermal systems to optimize the total electricity dispatch of an isolated mini-grid. The proposed approach estimates the hourly DHW load, and proposes and simulates different DR (demand response) strategies, from the supply side, to minimize the dispatch costs of an energy system.

The case study consists on optimizing the electricity load, in a representative day with low solar radiation, in Corvo Island, Azores. The DHW backup is induced by three different demand patterns. The study compares different DR strategies: backup at demand (no strategy), pre-scheduled backup using two different imposed schedules, a strategy based on linear programming, and finally two strategies using genetic algorithms, with different formulations for DHW backup – one that assigns number of systems and another that assigns energy demand. It is concluded that pre-determined DR strategies may increase the generation costs, but DR strategies based on optimization algorithms are able to decrease generation costs. In particular, linear programming is the strategy that presents the lowest increase on dispatch costs, but the strategy based on genetic algorithms is the one that best minimizes both daily operation costs and total energy demand, of the system.

1. Introduction

The increase in the use of micro-generation technologies has been introducing new challenges and opportunities to the electricity grid management. With the development of smart-grids, the consumers can also participate in the control of the load, but this requires new approaches to optimize the grid operation, such as demand response [1].

According to [2], DR (demand response) is voluntary and temporary adjustment of power demand taken by the end-user as a response to a price signal, for example market prices or tariffs, or taken by a counter-party like the utility based on an agreement with the end-user. The use of demand response strategies is a way to increase the flexibility of the grid management, as it allows the rescheduling of part of the load, adjusting the demand to the supply, deferring the need to invest more in capacity [3].

In small and isolated systems, like islands or remote communities, where the residential sector often represents the largest share of energy demand [4], the access to goods, including energy resources, is in general limited. In these cases the reliability of the grid operation is a critical aspect, especially when integrating renewable energy supply. The use of demand response strategies may help to deal with the intermittency of renewable resources, by contributing to the balance of demand and supply, thus minimizing operation costs and inducing a more reliable grid management [5]. As claimed by many authors [6,7], renewable integration can be further optimized, if storage systems are coupled with demand response in order to enlarge the load shifting capacity.

In Ref. [8], the reschedule of water heaters is identified as one of the demand response strategies with largest potential on the residential sector. In order to study the potential of the electric backup of residential thermal storage as demand response strategy in isolated systems, the authors discussed in Ref. [9] the impact in the overall electricity load, in the small island of Corvo, Azores. Similarly to electric vehicles and their capacity to absorb energy from the grid, acting as a demand response agents, hot water tanks can also be used for peak power shaving or load shifting, acting as a

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http://dx.doi.org/10.1016/j.energy.2015.01.054
0360-5442/

storage system and helping (if it is the case) to smooth renewable integration [10,11].

In Ref. [7], there is an extensive review of demand response strategies and techniques, but most of them consider the end-user point of view, based on the use of feed-in tariffs in order to change their normal demand pattern. From the utility point of view, to optimize the load management, Ref. [12] uses a multi-objective integer linear programing approach while [13] uses genetic algorithms. This paper proposes and analyses of the impact of different demand response strategies from the grid operation point of view. The objective is to minimize the island's energy generation and dispatch costs, avoiding high power peaks and achieve lower operational costs. In particular, it introduces new approaches based on linear programming and genetic algorithms to implement a demand response strategy of residential thermal storage.

The paper is organized as follows. Section 2 describes the problem statement and presents the characteristics of the case study. Section 3 introduces the models used for optimal electric dispatch and for quantifying the domestic hot water backup impact on the grid. Section 4 presents the different optimization strategies to implement the demand response strategies. The results are presented and discussed in Section 5, and Section 6 draws the conclusions of the work.

2. Problem statement of the case study of Corvo Island

The challenges of grid management and electric dispatch in small and isolated grids with renewable micro-generation systems, have been the scope of many recent studies and implementation projects [4]. This paper proposes to minimize the economic dispatch of an isolated system using a demand response approach to manage the domestic hot water electricity backup loads. The use of a DR program may have the additional benefit of delaying the investment of increasing the installed thermal generation capacity, to deal with the higher peaks. For that purpose, different optimization strategies of hot water backup are tested, in order to minimize the costs of the Corvo Island electricity generation and dispatch, from the grid manager point of view.

The analysis of the demand response strategy is done using the case study of Corvo Island, an isolated island in the middle of the Atlantic Ocean, with 430 inhabitants living in 144 houses [14]. At the moment Corvo Island, is externally dependent on energy resources, particularly diesel to supply the electricity generation power plant, with an installed capacity of 536 kW [15]. On the other hand, the recent replacement of gas boilers systems to generate domestic hot water, through the installation of 66 solar thermal systems and 78 heat pumps, has been a step forward to achieve energy autonomy, by assuring the continuous supply of DHW that, in the past, suffered from shortcoming of LPG (liquefied petroleum gas) to the island [9].

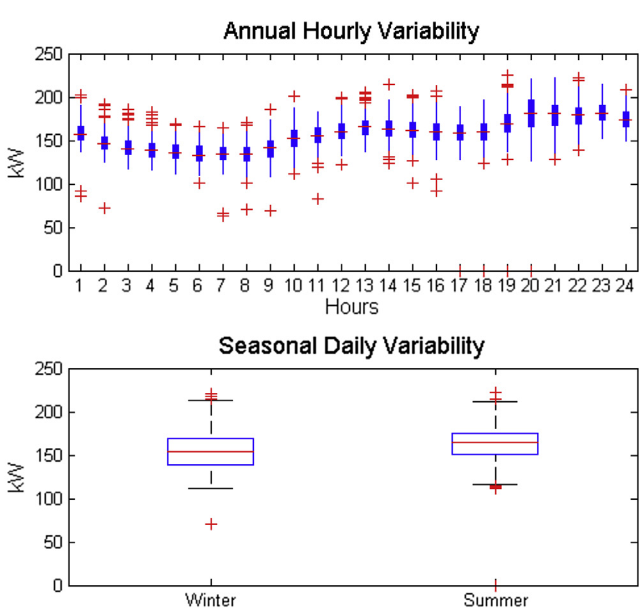

Fig. 1. Daily load diagram for Corvo Island: 2012 hourly variability; Winter and Summer daily variability.

The annual load of the island, prior to the electrification of DHW, was around 1.4 GWh with a daily peak of 225 kW and a daily consumption of 3.8 MWh. The load diagram is similar in weekdays and weekends, which is explained by the absence of industry in the island and the existence of few service buildings. The 2012 average daily load diagram is shown on Fig. 1, with the annual hourly variability and daily seasonal variability. The peak power is observed at dinner time, and the variability is similar from Summer to Winter, being the average load higher in the Summer but the maximum peak in Winter.

The electricity power plant of Corvo is composed of 4 diesel generators with the characteristics described in Table 1.

The DHW electric backup increased the overall island electricity demand [9]. However, it is important to guarantee that the peak demand remains within the power plant limits, otherwise an investment on additional generation capacity is required. In the case of Corvo Island, the generators should operate at least at 50% of their maximum load and the power plant has in general *N-1* generators in operation due to reserve requirements, requiring the use of demand response strategies. Therefore, if DHW backup could be evenly distributed over the off-peak period using a demand response program, it could contribute to guarantee the operation at the optimal operation point.

3. Modeling the optimal dispatch

In this section we present separately the two models that will work together to achieve optimal economic dispatch using DHW backup needs as demand response agent. First we derive the Economic dispatch model, using the operational and technical constraints which are used also in Corvo Island, and then we introduce the DHW electric impact model, also validated in Corvo Island in Ref. [9].

3.1. Economic dispatch model

In this work, we consider the use of an economic dispatch model that combines the unit commitment problem and the quadratic

Table 1
Diesel generators characteristics and constraints.

Generator	#1	#2	#3	#4
Total Base power [kVA]	135		200	
Nominal Power – Pnom [kW]	108		160	
Minimum power output [kW]	42		64	
Fuel Consumption [l/h]				
100% Pnom	31.2		49.4	
75% Pnom	24.2		37.4	
50% Pnom	17.4		25.6	
Minimum up time [h]	4		5	
Minimum down time [h]	2		3	
Ramp up/down rate [kW/h]	Inf		Inf	
Start-up cost (cold/hot) [€]	20/0		30/0	
Shut down cost [€]	0		0	
Working hours in 2012 [%/year]	49%	63%	49%	44%

Please cite this article in press as: Neves D, Silva CA, Optimal electricity dispatch on isolated mini-grids using a demand response strategy for thermal storage backup with genetic algorithms, Energy (2015), http://dx.doi.org/10.1016/j.energy.2015.01.054