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An optimisation algorithm for distributed energy resources management in micro-scale energy hubs

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A B S T R A C T

In this paper, a new algorithm for optimal management of distributed energy resources in facilities with distributed generation, energy storage systems and specific loads – energy hubs – is shown. This method consists of an iterative algorithm that manages optimal energy flows to obtain the minimum energy cost based on availability of each resource, prices and expected demand. A simulation tool has been developed to run the algorithm under different scenarios. Eight different scenarios of an energy hub have been simulated to illustrate the operation of this method. These scenarios consist of a demand curve under different conditions related to the existence or absence of renewable energy sources and energy storage systems and different electricity tariffs for grid supply. Partial results in the iterative process of the developed algorithm are shown and the results of these simulations are analysed. Results show a good level of optimisation of energy resources by means of optimal use of renewable energy sources and optimal management of energy storage systems. Moreover, the impact of this optimised management on carbon dioxide emissions is analysed.

1. Introduction

Energy consumption has been growing over recent decades. In order to minimise the dependence on fossil fuels, new energy resources are being integrated in energy systems [1], such as renewable energy sources (RESs) e.g. wind, solar, biomass and so on, and energy storage systems (ESSs). Also, new regulations have to be developed to support this integration [2]. Optimal management and control of the available resources is a key issue to be addressed and many research studies have been developed. Some of these works study optimal planning for new generation facilities [3]. In other works, optimal management is studied focusing on management of loads [4], i.e. demand side management (DSM). Some research studies are focused on DSM of individual facilities [5]. Conversely, in other studies, management of loads is studied at aggregator level, to optimise the global benefit [6]. Nevertheless, the optimisation problem may be studied from the perspective of energy generation facilities management [7], since modern facilities include more and more distributed energy resources (DERs) that must be managed to get the maximum benefit from them, i.e. the lowest energy costs.

A facility with multiple energy sources that has energy production, conversion and storage technologies (RESs, batteries, ice storage, hydrogen cells and so on) to supply electricity (and other services such as heating or cooling) is widely called an energy hub [8]. From the perspective of end users in energy hubs, optimal management of their available resources consists of controlling all energy flows in their facilities (between power grid, distributed generation resources, ESSs and loads) to minimise the total energy costs. Therefore, these facilities require reliable energy management systems (EMS) with real-time data acquisition and processing from energy resources and external variables (e.g. temperature, wind speed or energy purchase prices) and sophisticated algorithms to achieve an optimal management of the available resources along the time.

Over the past years, various algorithms to find an optimal solution of energy operation in energy hubs have been proposed. For example, Ref. [9] shows a multi-objective optimisation method applied to manage several generators in a microgrid. So, some algorithms have been developed to optimise overall costs by managing ESSs to purchase energy for microgrids with several available sources [10]. Many studies indicate that the impact of RESs is greater when ESSs are installed, as the unpredictability of these resources has a lower impact on the optimal solution [11]. In fact,

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Nomenclature

Acronyms

DER	distributed energy resource
DEROP	distributed energy resources optimisation (name of the proposed algorithm)
DG	distributed generation
DSM	demand side management
ESS	energy storage system
LabDER	Laboratory of distributed energy resources
MILP	mixed integer linear programming
PV	photovoltaic
RES	renewable energy source
UPV	Universitat Politècnica de València

Superscripts

(i)	iteration in the DEROP algorithm. From (0) to (f)

Subscripts

j	time index in the simulation period. From 0 to $N-1$
k	energy resource index. From 1 to n

Parameters, variables, and functions

T	Duration of the simulation period
N	Number of intervals in which the simulation period is divided
n	Number of energy resources in the energy hub (generation and storage resources)
f	last iteration of DEROP algorithm
τ	simulation step size, length of each simulation interval
t_0	initial time in the simulation period
t_j	instant in which the jth simulation interval ends ($j>0$)
d_j	total power demand at instant t_j
p_{jk}	power provided by resource k at instant t_j
q_{jk}	associated cost of resource k at instant t_j
Q_j	total cost of generated power at instant t_j
S	schedule consisting of a $N \times n$ binary matrix that indicates the state of each resource at each simulation interval
C_j	total cost of supplied energy during the interval $[t_j, t_{j+1}]$
C	total cost of energy during the simulated period
A_{jk}	mean available power of resource k during the interval $[t_j, t_{j+1}]$
p_{in}	effective power that batteries receive when they are charged
A	available power used to charge batteries
η_c	efficiency of the battery charging process
$W_{st(j)}$	total energy stored in batteries at instant t_j
p_{out}	effective power that is extracted from batteries when they are discharged
p_{bat}	net power that batteries lose when they are discharged
η_d	efficiency of the battery discharging process
$W_{out[t_j,t_{j+1}]}$	energy received by loads from battery during interval $[t_j, t_{j+1}]$

ESSs are key elements to reduce energy costs in facilities by reducing peak load or to help successfully incorporate distributed generation (DG) as shown in Ref. [12].

However, despite the interest of researchers in finding an optimal solution to systems operation, most of the developed optimisation methods are focused on DSM as in Ref. [13], by developing demand response programs and efficient management of loads. Others are focused on optimal planning for smart grids, in which some aspects might be relevant, such as topology, energy transmission, reliability of supply, and so on. For example, Ref. [14] shows an algorithm to optimise the capacity of batteries to be installed and diesel generators in an energy hub. Moeini-Aghtaie et al., [15] shows an optimisation algorithm to compute the economic dispatch in a grid with several energy hubs. Rastegar and Fotuhi-Firuzabad [16] describes an algorithm to achieve optimal management of energy resources and loads along a day. However, only linear functions are used in this algorithm.

In this paper, a new algorithm to achieve an optimal management of the available energy resources in energy hubs is proposed. The main target of the new DERs optimisation algorithm (DEROP) is to minimise energy costs by maximising RESs generation and optimising the management of ESSs. Some advantages of DEROP are that it allows considerable energy cost reductions, with a simple procedure and a fast computation algorithm. DEROP is flexible to be used under a wide range of situations with many different DERs and with different purposes, including non-linear functions for costs and efficiency of each resource. So, DEROP is easy to be implemented as an online service for end users.

This paper is organised as follows. Section 2 describes DEROP algorithm, which has been developed to achieve an optimal control of the available resources in energy hubs. All aspects related to DEROP algorithm and its features are shown in this section. Section 3 defines the scenarios to be simulated in order to show the performance of DEROP algorithm and the simulation tool. Section 4 shows the results of multiple simulations carried out with DEROP algorithm and the developed tool. These results are compared, analysed and discussed in this section. Finally, some conclusions to this work are drawn in Section 5.

2. Methodology

As aforementioned, most algorithms to optimise management of energy resources are focused on DSM. Others are focused on DG resources management, but they assume linearity in costs and efficiencies. Due to this reason, this paper shows DEROP algorithm, which optimises DG and ESSs management allowing non-linear functions. Fig. 1 shows the concept of an energy hub where DEROP algorithm would enable energy cost minimisation to meet a fixed demand curve.

DEROP algorithm calculates the cost of the total consumption from grid supply under a set of conditions and it iterates with some modifications in the energy supply schedule attempting to reduce this cost until reaching an optimal situation where no improvement is possible. Each generation resource has a different cost depending on the raw material and time. The aim of this algorithm is to optimise the operation of energy resources in an existing facility. As the main goal is not to plan the installation of generation or storage systems, in this experiment, only energy costs are taken into account. Therefore, for PV panels and wind generator, only costs for maintenance operations are considered since these resources do not need any raw material. This guarantees that the algorithm will maximise the use of these sources. As regards ESSs, a variable cost may be associated with these systems, depending on the charging and discharging profiles.

For a simulation of length T, a simulation step size τ is chosen and a set of N identical intervals are taken of a length