Scalable computational framework using intelligent optimization: Microgrids dispatch and electricity market joint simulation

João Soares*, Tiago Pinto*, Filipe Sousa*, Nuno Borges*, Zita Vale*, Andrea Michiorri†

* GECAD – Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development Polytechnic of Porto (IPP), Porto, Portugal (e-mail: {joaps,tmcfp,ffeso,ndsbs,zav}@isep.ipp.pt).
† MINES ParisTech, France, (andrea.michiorri@mines-paristech.fr)

Abstract: Worldwide microgrid capacity is expected to reach 7 GW and a market value of $35 billion dollars in the next few years. The decentralization of the generation dispatch role and different ownership models concerning microgrids, will contribute to increase the complexity of the future power systems. Analyzing new policies and strategies as well as evaluating those impacts is only possible with the use of sophisticated simulation tools. This paper presents a scalable computational simulation to address microgrid dispatch and the impact in the electricity market. Computational intelligence techniques are integrated to improve the effectiveness of the simulation tool. These techniques include CPLEX; differential search algorithm and quantum particle swarm optimization. Each microgrid player is able to solve a day-ahead scheduling problem and submit bids to the electricity market agent (spot market), which calculates the market clearing price. The developed case study with a large number of players totaling about 150,000 consumers suggest the relevance of the developed computational framework.

© 2017, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.

Keywords: agent-based, demand response, market, microgrid, simulation, stochastic optimization.

1. INTRODUCTION

Interest in microgrids has been growing significantly over the past few years. The primary reasons for these developments are related to cost reduction, high reliability (e.g. military installations), renewables integration, emissions reduction, investment deferral and policy targets. In United States alone, microgrids already represent an operational capacity of 1.54 GW according to (Walton 2016). It is expected that the global capacity reaches 7.6 GW 2024 (Navigant Research 2016) and over $35B market value by that time (Transparency Market Research 2014). Ownership models may vary widely but mainly involve end-users (usually communities), utilities and municipalities (Soshinskaya et al. 2014). The co-ownership agreements between different players will contribute to push this market forward.

In order to achieve efficient and low cost operation, energy resources should be managed in a completely different way from what was usual so far. In this scope, the Smart Grid (SG) paradigm arises, as the most commonly accepted solution for this problem (Lund 2014). The distributed management approach supported by SG boosts the emergence of several innovative energy resource management approaches. The penetration of a large number of electric vehicles is one of the most important topics in this domain, due to the large dimensionality that it brings to the optimization problem. This problem is usually solved using meta-heuristics, namely with simulated annealing in (Sousa et al. 2014) and with a novel multi-dimensional signaling method, in (Soares et al. 2016). A solid survey on this theme, with an overview of different perspectives to address this problem can be consulted in (Iqbal et al. 2014; Hu et al. 2016). The effects on the microgrid and distribution network operation has been studied in (Tsikalakis & Hatzigiargyriou 2008). The results indicate that microgrid operation leads to reduced energy prices for the consumers or increased revenues for the aggregator. The aggregation of the distributed generation (DG) units to form a microgrid under the coordination of a central controller can provide optimal cooperation of the production of the DG sources and the energy requested from the upstream distribution network (Tsikalakis & Hatzigiargyriou 2008). A successful experiment based on multi-agent system has been applied to energy resource scheduling of integrated microgrids and lumped loads (Logenthiran & Srinivasan 2012). The system is able to operate three microgrids and five lumped loads at minimum cost using genetic algorithms. The impact of different sources of uncertainty is also explored, such as the works presented in (Su et al. 2014; Eajal et al. 2016; Ju et al. 2016; Baringo & Conejo 2016).

Although a significant amount of work is being done in this domain, the large majority of the performed studies lack the ability of replicability and scalability while being focused on a small part of the system and inhibiting too further understand its implications as a whole. This is mostly because SG are still an emerging reality, and thus, practical implementations are still not sufficiently widely spread. Even when considering the real implementations that are available, the execution of innovative experimental studies is difficult, because of the implications on the several users that are present in the real environment.

In this paper a scalable computational simulation to address microgrid dispatch and the impact in the wholesale market is proposed. The proposed simulation is computationally efficient and allows to evaluate the effects of large number of players (microgrids) in the electricity market as well as to refine business models and improve dispatch algorithms. To achieve this objective, deterministic and modern metaheuristic
optimization are implemented to offer the most appropriate solution. The main idea is that each player is able to solve a day-ahead scheduling energy problem taking into account its context while achieving reasonable simulation time. In addition, multi-agent system for competitive electricity markets (MASCEM) simulator (Santos et al. 2016; Vale et al. 2011) has been used in the proposed work to analyze the electricity market impact of the involved microgrid players.

After this introductory section, section 2 presents more details regarding the proposed simulation, including the proposed algorithms and the electricity simulator mechanism. Section 3 presents a case study simulation. The results are given in Section 4. Finally, in Section 5, the most relevant conclusions are presented.

2. SCALABLE SIMULATION

In this section, the proposed simulation is described, namely introducing the envisaged dispatch problem, the optimization algorithms, the mechanism to select the suitable method to run the microgrid dispatch, and the market simulation.

2.1. Day-ahead dispatch

The day-ahead dispatch model is based on a recent work (Soares et al. 2016), namely a multi-period optimization with 24 periods, each representing 1 hour. The objective function is represented by (1):

\[
\text{Maximize} \quad P_{\text{Total}}^{D+1} = OC_{\text{Total}}^{D+1} - I_{\text{Total}}^{D+1}
\]  

where \( P_{\text{Total}}^{D+1} \) represents the expected day-ahead profits; \( OC_{\text{Total}}^{D+1} \) represents the expected day-ahead operation costs; and \( I_{\text{Total}}^{D+1} \) represents the expected income of the microgrid.

The income of the microgrid are obtained from the energy sale to consumers, EVs and storage revenue and the expected market sales income. The operation costs sources are: DG units operation, energy suppliers, demand response programs, storage and EVs discharge and the market bids. It is assumed that the microgrid is able to buy from the wholesale market but also can buy energy to external sources, such as an energy retailer. The benefit is that the microgrid can rely on a certain price, which is agreed previously by contract. It enables the microgrid to buy additional energy it cannot negotiate in the market.

The constraints of the model consider the generation limits of each device, the limit of demand response reduction for each consumer, the EVs and storage capacity and power rates as well the external suppliers’ contracts constraints. These constraints have already been developed in the literature where the reader can rely on to understand the dispatch model (Soares et al. 2015; Soares et al. 2016; Morais et al. 2015).

For simplification purposes the same microgrid model was considered for each player in the simulation environment. The results will be used as inputs in the electricity market service.

2.2. Optimization algorithms

The optimization algorithms are an important part of the simulation platform. In order to have a scalable simulation, it is necessary that the optimization algorithms are able to run smoothly and without interruptions, i.e. being able to handle very large problems (in terms of variables and constraints). For example, a microgrid scheduling problem might reach thousands of variables when considering many controllable energy equipment. Therefore, a set of diversified techniques is proposed in the simulation to handle the dispatch problem within required time more efficiently and effectively. The optimal problem is a mixed integer nonlinear problem, but it is linearized in this paper and formulated as mixed integer linear programming (MILP) to increase computational performance. The MILP model can be solved using a traditional CPLEX deterministic solver. In addition, stochastic optimization has been integrated into the simulation platform, namely two metaheuristics have been incorporated. These metaheuristics are differential search algorithm (DSA) and quantum particle swarm optimization (QPSO). These algorithms have demonstrated to be very successful in power system applications (Civicioglu 2012; Soares et al. 2016).

A) Differential Search Algorithm

The DSA is a new metaheuristic that demonstrated to be effective in several benchmark problems (Civicioglu 2012). DSA algorithm is inspired in the nature, in this case in the migration of living beings. The population in DSA corresponds to a superorganism migrating to a global optimum solution of the problem. However, it is not guaranteed to find the global optimum like in any other metaheuristic. In the course of this migration, the superorganism tests whether some randomly selected positions are suitable for temporarily basis. If the tested position is suitable, the members of the superorganism that made this discovery immediately settle at the discovered position. This position is suitable if it is better than other positions previously found.

A member of a superorganism, in its initial position, is generated between the upper and lower bounds of the problem variables as defined by the equation (2):

\[
X_i = \text{rand} \cdot (up^i - low^i) + low^i
\]  

The expression for a stopover site position is given by the equation (3). DSA has only two control parameters \( p_1 \) and \( p_2 \), which control the process of morphogenesis (a map of active mutations). Direction is the evolution of the superorganism.

\[
\text{Stopover} = \text{Superorganism} + R \cdot \text{map} \cdot (\text{direction} - \text{Superorganism})
\]  

The scale factor \( R \) in equation (4) can be defined by a random number using a gamma distribution \( \Gamma \) with a shape parameter in \( A \) and scale parameter in \( B \), simulating a pseudo-stable walk movement. Actually, the generated scale factor \( R \) is fundamental to control the magnitude of the change in positions of the members of the superorganism.

\[
R = \frac{1}{\Gamma(A,B)}
\]  

B) Quantum Particle Swarm Optimization
دریافت فوری
متن کامل مقاله
امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات