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A day-ahead energy market simulation framework for assessing the impact of decentralized generators on step-down transformer power flows

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ABSTRACT

The world wide expected high penetration levels of distributed generation technologies (DG) will modify the operation paradigm of power systems. In this context, this work presents a day-ahead simulation framework to predict, in quarter hour periods, the step-down transform power flow linking the interconnected power system with a distribution network highly penetrated by DG. The capability of integrating in a single platform the simulation of different types of loads, DG technologies and the network at both local and system levels, is recognized as the novel contribution of this work. By using an object oriented approach, different models have been integrated to represent the behavior of the DG. These models include weather changes, load management programs, and contract agreements between customers and suppliers. For the representation of loads, a clustering technique is used. Special attention is devoted to the representation of combined heat and power units and their dependency on weather conditions. Validation of the method and a practical application of the simulation framework to a case study, built with realistic data from German and Chilean distribution systems, are discussed. The results show the potential of the tool in the field of power system operation planning from both, the transmission and the distribution company point of view.

1. Introduction

Distributed Generation (DG) can be defined as the integrated use of small generation units directly connected to a distribution system or inside the facilities of a customer [1,2]. Trends observed in some power markets suggest that in the future, a substantial share of electricity will be produced by technologies associated with DG in distribution and subtransmission systems [3]. These technologies encompass a wide range of subcategories characterized by fuel type, generation capacity, multiproduct capability, environmental impact and operation flexibility [4]. In the near future it can be expected that ultracapacitors, advanced flywheels, superconducting magnetic energy storage, and hydrogen production units will be integrated into many DG applications [5]. These applications allow intermittent renewable energy storage, bulk power system peak shaving, load leveling, and reserve management.

Increased use of DG will place higher uncertainties in the operation, due to their dependency on meteorological variables (i.e. wind and water inflows) and their operation strategies or modes, which are difficult to forecast. This imposes new challenges for the system operation management.

On the other hand, the structural changes, that have been associated with the arrival of competitive power markets, have placed higher requirements on day-ahead demand estimation. This is due to a more intensive participation of customers in the operation of the system, which is associated with more dynamic retail markets. An increasing problem in this area has been related with the privacy of information, as all players are competitive companies [6,7]. However, market agents share a common need for efficient system operation and prices, seeking profit maximization and risk minimization regarding price spikes [8,9].

To present the problem addressed in this paper, Fig. 1 shows a typical scenario, where different DG units and customers, at distribution level, are supplied by an interconnected system through a step-down transformer.

The curves on top of Fig. 1 correspond to the step-down transformer's power flow. The upper curve shows the situation without DG units. In this case uncertainties are mainly related to load behavior. However, when DG is incorporated in a large scale the resulting transformer power flow can experience a significant reduction. This situation is represented by the lower curve in Fig. 1. In this case, uncertainties increase as DG power injections depend on meteorological variables and independent operation

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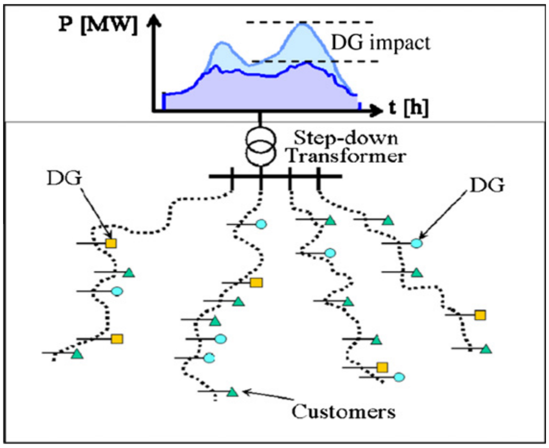

Fig. 1. Supply scenario with DG modeling.

modes of each unit. Therefore, the evaluation of the DG impact on step-down transformer's power flow is nowadays a complex task.

Moreover, DG integration has also promoted implementation of new concepts such as active or passive networks, for the operation of the first ones; Pecas et al. [10] propose a control approach that has two functional blocks: state estimation and control scheduling. The state estimation block uses the network electrical parameters, network topology, load models and real-time measurements to calculate a network state estimate, identifying the importance of load models to improve the network operation and planning. Thus, in order to evaluate the impact of DG connection to distribution networks on existing feeder and/or transformer reinforcements facing the natural load growth in the medium and long-term, Méndez et al. [11] deal with the net demand, which is calculated as the difference between the total load demand and the total energy production from DG connected to the network in each hour. For the previous works, demand modeling is performed for the whole feeder following consumption patterns. Other techniques to forecast demand behavior are based on ANN that can consider weather effects, like the one presented in [12].

Qian et al. [13] focus on the impact of load models on power loss calculation in DG planning. The main contribution is to investigate the impact of detailed load modeling on DG planning. The results presented help to understand the influence of each parameter that might affect power losses with the integration of DG on distribution feeders. Load models are constructed on three types of consumer patterns while DG are basically fuell cells and microturbines avoiding the uncertainty of those based on renewable energy. In [14], optimal capacity of PV and energy storage systems is discussed, the approach considers three types of consumers (industry, commercial building and shopping center), the load modeling consist of making use of historical consumption patterns while the PV generation is estimated based on solar radiation measurements. Complementary, Yamaguchi et al. [15] present a district energy system simulation model which contains a detailed energy demand model. This model adopted the bottom up approach in which the energy flow of a district is modeled as the sum of total energy input and output of each building. In this model, heat and power demands of each building are simultaneously calculated considering climatic conditions, occupant behaviors, use of appliances, adoption of energy saving measures, and etc.

This paper proposes a novel simulation framework for the estimation of the day-ahead step-down transformer power flows, with an explicit incorporation of DG technologies and their operation modes. The proposed framework encompasses several deterministic simulation models, together with a fuzzy clustering tool, which is used to model customer loads. The load flow forecast at the desired voltage level is the result of a bottom-up approach, obtained by the aggregation of different load profiles of customers that are supplied down-streams, and the accounting of the expected power delivered by DG.

The paper is organized in five sections. In Section 2 the proposed model for the network components, customers and DG units is described. Section 3 presents the proposed simulation framework and its integration into an object-oriented based decision support system. Section 4 presents the validation of the proposed model and its application within a realistic case study. Finally, Section 5 summarizes the main conclusions of this study.

2. System modeling

In order to achieve the proposed framework, three aspects are considered:

- System components.
- Customer models.
- DG Operational modes and technology models.

2.1. System components

The object oriented approach represents the state of the art in software analysis and design. It offers a flexible method to model the characteristics and behavior of the network components from a system point of view, including the DG technologies previously presented [6,16].

The system representation is carried out through three object oriented databases [6,17] (see Fig. 2). The equipment and component modeling is based on physical power system objects in the network database (NDB) and on hydro system components in the hydro database (HDB). On the other hand, a market database (MDB) contains market related objects like market actors and contracts.

Due to their high hydro generation dependency, an accurate HDB representation of hydro microturbines and their dependencies is an important issue in countries like Chile and Brazil. The individual characteristics of network, hydro and market elements are described by object attributes and the information exchange between objects and the operational behavior is performed by messages following the object-oriented programming paradigm. The object modeling technique in reference [18] has been used for developing the object models presented in this paper. One of the main advantages of the object oriented approach is the easy incorporation and extension of the model for new technologies, market actors and contract types. Furthermore, the methods related to the classes can be easily adjusted to new defined market and operation rules. Fig. 3a shows the hierarchy chart of the NDB. "NDB component" is the most general class and its attributes and methods are available for all subclasses [17]. Since simulation models are typically based on a node/branch-representation, these classes are explicitly included in the object-oriented data model. The class "Branch" is a child-class of the abstract class "2-Pole",

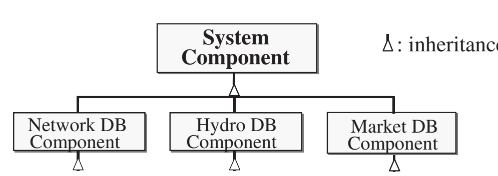

Fig. 2. Object model of the system.