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A dynamic model for distributed energy resource expansion planning considering multi-resource support schemes

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ABSTRACT

In this paper, a system dynamics based model is developed to investigate the impacts of multi-resource regulatory policies on distributed energy resource (DER) expansion planning. DERs usually include a variety of renewable and fossil based generation technologies such as wind and gas engine resources, combined heat and power (CHP), demand response (DR) and energy storage. The intermittent nature and uncertainty in power generation of some of these resources and other uncertainties that exist in the market environment would cause investors to encounter risk in their investment decisions. Implementation of any supporting policy affects any investor's behavior and investment level of other investors. Regulators should properly identify long-term impacts of their support policies in the energy resource expansion in order to choose a proper support scheme. These support schemes should ensure the long-term market stability. It is important for a DER investor to properly identify his/her long-term investment behavior to select an appropriate strategy. In this paper, the system dynamics method is used to investigate these issues. The impacts of various multi-resource regulatory policies on market dynamics are modeled and compared with the single-resource support schemes ones. In this study, support schemes are considered for supporting DR, wind resources, CHPs and photovoltaic resources.

Introduction

International Energy Agency in task 17 of strategic plan for demand side management has stated the necessity of planning for the expansion of distributed energy resources (DERs) [1]. This issue is important since the international community is decisively trying to reduce environmental pollution. Moreover, to achieve sustainable expansion in the field of electrical energy, diversification in the generation of energy resources is an obligation. This has led many countries to determine the penetration rate of these resources in their horizons programs.

DERs as small-scale generating units are usually located nearby the load points and consist of a wide range of technologies such as renewable energy resources, fossil-based technologies, energy storages and demand side management (i.e. demand response (DR)) programs [2].

In order to achieve the sustainable development of energy, policymakers suggest utilizing of DERs. They also believe that because of the diversification of resources and the importance of environmental issues, the penetration rate of these resources have to be increased in the presence of high values of investment costs and uncertainty. Therefore, if no supporting structure be provided on some of these resources, no funds will tend to invest on these technologies. In recent years, extensive researches have been conducted on DERs expansion planning, but they were very limited studies under the competitive environment with regard to the uncertain elements. DER expansion planning consists of finding answer to questions such as where, when, how much and what kind of DERs with what kind of support scheme have to be invested.

In traditional environment, in order to meet the demand growth, planning of generation expansion aims at reducing economic costs to achieve an optimum combination. Supplying power requirement with acceptable level of reliability is one of the system provisions and the focus is on offering power systems so that the demand side model is considered as a predicted load growth rate. Planning procedures in traditional power systems are in a way that decision makers are confronted with less uncertainty [3–9]. In many studies, besides minimizing costs of generation expansion, power loss, power supply from upstream network, and other objectives which include maximizing system reliability [10–12] or environmental aspects [13] have been simultaneously optimized. In these works, a multi-objective optimization has been done to solve DER expansion problem.

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Some investigations have been also conducted in the field of DER expansion planning in restructured environment. In such environment, the policymaker regulates supporting policies and investors attempt to invest in DERs in order to achieve their goals. In such circumstances, consumers can also participate as an energy resource through participating in DR programs. These demand side resources along with their unique features add to the complexity of the problem. Planning in this environment is no longer centralized and all players including system operators, generation companies, and investors have to plan based on their own strategy. Competition in the market and conflict between desires of participants, each of them pursuing their own interests, should be considered in some way. Therefore, investment in capacity expansion is the result of decentralized decisions taken by market participants. These decisions are made based on the feedback of electricity price signal, usually lack complete insight into future market conditions and are accompanied by inaccurate predictions with uncertainties. Ref. [14] has applied an innovative method and economic analysis to find optimum size and location of DERs from investor's point of view. Refs. [15–18] performed the expansion of DERs in the presence of uncertainties.

Due to increase of risk in restructured environment and high intermittency in output generation of some of these resources as well as high investment costs, if some technologies are not supported, they may not be able to compete with other technologies; consequently, no investor is willing to invest for developing these resources; therefore, they need some kind of support.

Previous researches have utilized optimization methods based on equilibrium point for distributed resource expansion. The investors' dynamic behavior and important market feedbacks are not taken into account in previous studies. The aforementioned methods did not also consider the deviation from long-term economic stability. Similar to many real economic systems, due to dynamic nature, generation resources do not encounter the required hypothesis that the system remains on long-run optimal trajectory at all the times [19]. It takes much time for electricity market to respond to a variation (e.g., electricity demand or network and bulk generation expansion) and to be updated with the new conditions. As a consequence, new models are required for managing the high level of risks associated with power system as a consequence of penetrating uncertain resources. Some of these uncertainties are as electricity price, fuel price, regulatory changes, competitors' decisions, generation of resources and etc.

In order to overcome the aforesaid challenges, applying some effective and descriptive methodologies seems to be necessary. System dynamics method as a strategic decision making tool can be useful due to its inherent characteristics. As a result, more actual perspective for strategic designing of power system can be achievable.

The system dynamics approach has been considered in bulk generation expansion planning [19–23], while it has not been addressed in DER expansion planning so far.

The system dynamics method not only models the market's real behavior but also properly explains the relationship between main variables of the system. Due to the presence of a portfolio of different energy resources in the problem of DER expansion planning and the point that any of them may be supported, the effect of each support on the penetration rate of other resources should be properly evaluated.

In this paper, the impacts of regulatory policies on market dynamics are modeled, which affect on behaviors and investment policies of resource owners. Here, a comprehensive model based on system dynamics is presented for analyzing the behavior of investors in the problem of generation expansion considering different uncertainties. In addition, the effect of policies on the market dynamic and investors' decisions are investigated. In this approach, each investor as a participant invests in one type of technology with the aim of maximizing his/her profit. Also, in this modeling, long term load elasticity is considered.

In [23,24], effects of policy maker's interventions as a single-resource support on the problem of generation expansion planning are investigated. However, in this paper, effects of policy maker's interventions as multi-resource support scheme are investigated and analyzed. The main contributions of this study is the utilization of system dynamics method to investigate long term effects of multi-resource regulatory support schemes and uncertainties of electricity market on distributed energy resources expansion planning. Also, Entrance of a demand side resource i.e. DR has not been investigated in previous researches. This paper presents a model and formulation that comprehensively fulfill how to model the mutual effects of resources and their support schemes on each other.

The rest of this paper is organized in the following order. 'DERs investment planning' describes the DERs investment planning description. In 'Modeling requirements', requirements of modeling are discussed, in 'Modeling of DER expansion planning', DER expansion planning is modeled. 'Numerical studies' is devoted to numerical studies and finally, 'Conclusions', concludes the paper.

DERs investment planning

In the restructured power systems, the policymaker is responsible for formulating policies in line with major governing objectives and investors desires in order to expand the capacity. To make a proper decision on this investment, long term behavior of the electricity market should be modeled. Signals of price and unpredictable market conditions are examples of uncertainties which exist in restructured power systems and make problem of developing resources more complicated. To overcome these problems, in this paper, a model is proposed for decision making on the expansion of energy resources based on system dynamics approach. In the system dynamics method, in each step of solving differential equations, investment decision making will be made based on profitability index. Since this method is able to describe relations between system components, it can evaluate the impacts of policies and decisions on the long term behavior of the system. Details, advantages and limitations of this method can be found in [19].

The problem under study in this paper is a portfolio of distributed energy resources which feeds a predicted load in power network. State variables include capacity of each resource, predicted load, competitors' decisions and supporting policies. In this study, fuel cost, load growth, investment expenditures, interest rate, environmental considerations and market type are exogenous variables. The causal diagram which is a scheme of cause and effect relations between various components of the system is a good tool for modeling the interaction of system variables. Fig. 1 illustrates the causal diagram of this problem. The main input and output parameters of the problem are also provided in Table 1.

Main loops in this model are as follows:

- Demand loop.
- Capacity loop (related to the self and rivals).
- Supporting policy loop.

The most important loop is the "demand loop". The demand is influenced by the change in electricity price so that, in each period, high price of electricity causes decrease in demand and vice versa. The capacity loop is a balance loop for demand loop on the generation side. This loop indicates the investment and construction of new generation units. In addition, there is an "operation scheduling loop" on the generation side as well. Using this loop,