Information gap decision theory to deal with long-term wind energy planning considering voltage stability

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ABSTRACT

This paper proposes a novel approach for long-term planning of wind energy considering its inherent uncertainty. The uncertainty of wind energy is handled via information gap decision theory (IGDT) method. Additionally, due to the importance of security considerations, loading margin is employed as an index of voltage stability to guarantee the security of power system. The operational constraints (such as power flow equations) in initial operation point considered along with those at the voltage collapse point, simultaneously. Accordingly, the IGDT-based voltage stability constrained wind energy-planning model is proposed that can be used for ensuring the safe operation of power networks. The main feature of this model is to handle the uncertainty of wind energy in the long-term wind energy planning via IGDT technique, by considering voltage stability constraints. In order to evaluate the capability of the IGDT technique for uncertainty handling of wind energy, the obtained results are compared with Monte Carlo simulations. To demonstrate the effectiveness of proposed model, it is applied to the New-England 39-bus test system. The obtained results validated the applicability of the proposed model for optimal wind energy planning. The proposed methodology could help wind farm investors to make optimal large-scale wind energy investment decisions.

1. Introduction

Due to serious concerns regarding the increasing environmental pollution caused by thermal generation units and risk issues of nuclear power generation, renewable energy sources have become superior energy to supply electricity demand. Among the renewable energy resources, wind power generation (WPG) has attracted the attention of power system operators and investors. On the other side, inappropriate planning of wind energy will pose power system to serious safety issues. One of the major barriers against high penetration of wind energy is the uncertainty associated with this renewable energy technology. Under such circumstances, the uncertainty associated with wind energy may cause some problems for wind farm (WF) owners’ when they come to make investment decisions. The WPG uncertainty is one of the serious challenges that endangers the stability of power system, especially voltage stability which should be considered in planning stage of this type of renewable energy. Due to the importance of mentioned attractive concepts, researchers have worked on different dimensions of power systems under the influence of wind energy. In the following section, the existing literature is reviewed to build a backgrounds on voltage stability, wind energy planning (WEP) and uncertainty modeling of WPG.

Nowadays many power systems are operated very close to their voltage stability limits which will makes them vulnerable to voltage instability phenomena [1]. In this way, the concept of voltage stability has been investigated in different research works. The authors in Ref. [2], proposed a corrective voltage control scheme in order to guarantee the security of power system in normal and severe contingency conditions considering the desired loading margin. In Chang’s work [3], the modal analysis method is used for optimal allocation of flexible ac transmission system in order to increase loading margin and decrease system expansion costs as a multi-objective problem. The voltage stability and reliability of power system were evaluated in different DG power generation scenarios [4]. The static and dynamic voltage stability analysis were carried out in Ref. [5], for planning of reactive power compensators in order to enhance the voltage stability of network with distributed wind energy generation. In Ref. [6], voltage stability and
reactive power losses were simultaneously optimized as a multi-objective problem and best compromise solution was selected via fuzzy satisfying approach. The author of [7], proposed a methodology to find the critical transmission lines and rate of power that could be injected to the grid by series compensations in order to increase loading margin of the network.

Several constraints have been considered in WEP literature. For example, the operational constraints considered for planning of wind energy in Ref. [8]. Also, Author of [9] proposed two optimization algorithms for planning of wind energy, while market constraints were considered as well in planning model. Furthermore, in Ref. [10], important factors for planning of wind energy were investigated and reviewed from different planning aspects.

Several methods for uncertainty modeling of input parameters have been developed such as Information gap decision theory (IGDT) [11], Monte Carlo simulations (MCS) [12], point estimate method [13], scenario based modeling [14], fuzzy logic [15] and robust optimization [16]. In Soroudi’s work [17], the uncertainty associated with investment and operation of WFs from the distributed generation operators’/owners’ perspective carried out by hybrid possibilistic-probabilistic method in order to assess the impact of wind energy generation units on technical performance of distribution network. Also, the authors in Ref. [18] proposed a risk averse decision making tool for preventive voltage control of joint AC/DC power systems taking into account the uncertainty of wind energy and load demand. Conditional value at risk is utilized information of probability density function of uncertain parameter.

Among the uncertainty modeling techniques, the IGDT is one of the practical methods that can be used for handling the uncertainty of wind energy to avoid problem caused by this phenomena. This method has specific properties that make it superior. For example, in comparison to stochastic techniques, this method does not need information of probability density function of uncertain parameter.

### Nomenclature

**Sets**

- \(N_D\): Number of years for delay of investment
- \(D\): Demand levels in a year
- \(T_f\): Planning horizon
- \(N_{FB}\): Proper buses for wind farm (WF) installation
- \(N_B\): System buses
- \(X\): Set of all decision variables
- \(NG\): Thermal generating units
- \(NL\): Transmission lines

**Indices**

- \(d\): Demand levels index
- \(t\): Index of investment years
- \(b\): System buses index
- \(l\): Transmission lines index
- \(i\): Thermal generating units’ index
- \(W\): WFs index

**Variables and Parameters**

- \(P_{b,t,d}/Q_{b,t,d}\): Active/reactive power load of bus \(b\) in year \(t\) and demand level \(d\) (per unit (pu))
- \(P_{b,t,d}^w/Q_{b,t,d}^w\): Active/reactive power of WF \(w\) injected to bus \(b\) in year \(t\) and demand level \(d\) (pu)
- \(P_{G,t,d}/Q_{G,t,d}\): Active/reactive power generation by \(i\)th thermal generation unit in year \(t\) and demand level \(d\) (pu)
- \(P_{L,t,d}^-/Q_{L,t,d}^-\): Active/reactive power of load \(b\) in year \(t\) and demand level \(d\) at VCP (pu)
- \(P_{L,t,d}^+/Q_{L,t,d}^+\): Active/reactive power generation by \(i\)th thermal generation unit in year \(t\) and demand level \(d\) at voltage collapse point (VCP) (pu)
- \(MVA_{base}\): Base power (MVA)
- \(CF_{bc}\): Capacity factor of WF in base case (BC)
- \(CF\): Capacity factor of WF
- \(i_{b,t}\): Cumulative wind power capacity of WF \(w\) connected to bus \(b\) up to year \(t\) (pu)
- \(\beta\): Critical value of profit to be maintained at presence of uncertainty in the RA strategy ($)
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