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Probabilistic assessment of wind turbine impact on distribution networks using linearized power flow formulation

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ABSTRACT

The attractiveness of renewable energy resources has convinced the power system operators to utilize their cheap brought up energy as much as possible. Continuously, the integration of renewables, especially wind based ones, has been followed up in distribution networks as well as transmission scale. The main challenge that comes up with increasing of this integration is uncertain generation of these resources, which affects the networks parameters and optimization strategies. Consequently, studying the approaches, which focus on handling these uncertainties deserve special consideration. Two main features of time and accuracy are the most important evaluation criteria of these methods. The most accurate approach of Monte Carlo simulation suffers from high computational time, which makes it inapplicable to problems, which needs more swiftness. In the other hand, decreasing the time increase the results error that may cause to incorrect decisions. In this atmosphere, proposing a method, which provides suitable trade-off between these two criteria, can be so valuable. This paper, proposes the utilization of a set of accurate linear power flow equations in simulation of probabilistic methods, which brings out so considerable swiftness. In this paper, the linear power flow equations have been proposed for modeling the distribution network instead of typical Newton-Raphson approach, which decrease the computation time per each simulation. Implementation of these equations in MCS method results in lower error in compare with the well-known approaches of two points estimate and Latin hypercube sampling methods where its swiftness is compatible with them. Using proposed equations in two points estimate method and Latin hypercube sampling methods makes them so faster which prepare them for online probabilistic analysis of distribution network. Finally, two standard test systems of IEEE 33-bus and 69-bus have been employed for validation of proposed method.

1. Introduction

Nowadays, incremental electrical energy demand with limited transmission lines capacity in addition to environmental issues have led to high attention to distributed generation (DG) topic which has approved that it can be suitable solution for mentioned problems [1,2]. DGs as the small generation units are so beneficial for power systems. Some of these benefits can be categorized in: reducing the energy loss, voltage profile improvement, arising the system efficiency, enhancement the reliability and so on [3,4]. These advantages have caused the application of DGs, increasingly. Various kinds of DGs have been used widely, but global energy crisis causes paying more attention to the renewable energy based DG sources than other types in recent years. This progressive movement toward renewable can have a lot of reasons, like as augment of energy self dependency in countries [5].

One of the important renewable energy DG sources is wind energy based DG. However, a lot of studies have been done about wind DG and its impact in power system's transmission scale [6,7], but it seems that the wind DGs impact on distribution network has not been discussed a lot in compare with transmission scale.

Different aspects of wind DG presence's effect in distribution network have been studied in literature. Reference [8] searched for strategies that can maximize the penetration of wind power on distribution network. This study shows that three schemes of wind power curtailment, reactive power management and coordinated voltage control can increase the renewable power's penetration. Optimal placement of renewable DGs in distribution network has been done in [9] using evolutionary based algorithm. The authors of [9] have applied sensitivity analysis and the feasibility checking index of population generation to reduce the computation time, as well. Optimal allocation of renewable energy sources with the aim of distribution network loss reduction has been followed up by [10]. Reference [11] investigates increasing the hosting capacity of wind energy in distribution network and minimization of network loss simultaneously. Demand response program

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Nomenclature

k	index of system bus
V_k	kth bus complex voltage
V_k^{re}, V_k^{im}	real and imaginary parts of kth bus complex voltage
I_L	Lth load complex current
I_L^{re}, I_L^{im}	real and imaginary parts of Lth load complex current
$a_{p,k}$, $b_{p,k}$, $c_{p,k}$	Zip model's active load coefficients for kth bus
$a_{q,k}$, $b_{q,k}$, $c_{q,k}$	Zip model's reactive load coefficients for kth bus
$P_{L,k}^0$, $Q_{L,k}^0$	consumed active and reactive powers of kth bus's load at nominal voltage
V_0	nominal voltage of system
I_L^P	constant power part of load's current
$I_L^{P,\mathrm{re}}$, $I_L^{P,\mathrm{im}}$	real and imaginary parts of constant power part's current
I_L^Z	constant impedance part of load's current
$I_L^{Z,\mathrm{re}}$, $I_L^{Z,\mathrm{im}}$	real and imaginary parts of constant impedance part's current
I_L^I	constant current part of load's current
$I_L^{I,\mathrm{re}}$, $I_L^{I,\mathrm{im}}$	real and imaginary parts of constant current part's current
V_s	system's slack bus voltage
R_b, X_b	bth line resistance and reactance
A, B	the weibull function's shape factor and scale factor
v	wind speed
P^w	generated active power by wind turbine
v_{in}^c, v_{out}^c	wind turbine cut in and cut out speeds
v_{rated}, P_r^w	wind turbine rated wind speed and rated power
M_i	ith uncertain variable
$\lambda_{i,m}$	mth central moment of ith uncertain variable
$\xi_{i,j}$	jth standard location of ith uncertain variable
$\omega_{i,j}$	jth weight coefficient of ith uncertain variable
K	number of uncertain variables
μ_x	mean of uncertain variable of x
σ_x	standard deviation of uncertain variable of x

has been suggested for increasing the network flexibility and as a control tool for distribution network operator in [11]. Comprehensive reliability assessment of distribution network in the presence of renewable energy sources has been presented in [12]. Reference [12] has studied the wind generation units impact on distribution network reliability and has proposed it as a solution to decrease the cost of power outage. Consideration of wind farm effect in the sizing and siting problem of static synchronous compensator to achieve the goal of distribution network transient stability improvement has been done in [13]. The [14] has presented a three phase linear power flow formulation for studying the renewable integrated active distribution network. Finally, [15] reviews the literatures which have studied the renewable sources integrated distribution networks. This review paper presents a comprehensive overview on the works which have investigated the environmental, economic and technical benefits of renewable sources integration on distribution networks.

As a fact of matter, the most challengeable part of renewable energy based DGs are their probabilistic generation behavior which makes them non-dispatchable. Some studies have focused on the impact of wind DGs on distribution network by considering the probabilistic nature of these generation units. In [16] the unbalanced distribution network voltage discussion has been done regarding wind DG uncertainty. Assumption of wind speed and load demand as the uncertainty sources and using Monte Carlo simulation (MCS) method for handling random input data have been presented in [16]. In [17] the probabilistic impact of renewable energy sources such as wind turbine generation and photovoltaic on distribution network has been studied. In [17], it is assumed that the uncertainty sources of system are the generation of renewable DGs and the every bus's load. Probabilistic nature of uncertain sources have been modeled by several famous methods. Reference [18] discusses the optimal planning of storage system with consideration of wind farms uncertainties in active distribution network. The investigation of renewable energy sources on distribution network power flow using backward/forward manner has been done in [19]. The [19] has utilized the Monte Carlo method for handling the solar irradiance, wind and load uncertainties. Reference [20] proposes a discrete convolution methodology for probabilistic load flow study of active distribution networks which embed renewable energy sources.

Typically, probabilistic studies suffer from the problem of high computational time consumption. The MCS method as the most accurate method in modeling the uncertainties includes the mentioned disadvantage. Whereas MCS method's results are assumed as the criterion of other methods assessment, but its time problem, makes it inapplicable to some of problems which the consumed time is important parameter, likes as online monitoring issues. Although, other methods have been proposed for reducing this time, but the inaccuracy of these methods should be accepted as the cost of brought up swiftness.

The point estimated method (PEM) and latin hypercube sampling (LHS) method are the approaches which have been proposed for compensating the time problem of MCS. These methods are based on lowering the number of samples which should be simulated to obtain probabilistic results. The utilization of these methods can be found in the literature. Reference [21] has focused on investigation of optimal power flow of distribution network including wind farms using two point estimated method (2PEM). This reference utilized 2PEM in the presence of correlated parameters where the Cholesky factorization manner has been employed for generating the correlation samples. It is worth to mention that 2PEM is special case of PEM, which selects only two points for each uncertainty sources. Reference [22] has proposed a probabilistic power flow method, which models the dependencies between random variables of load and power. The proposed problem has been solved using extended PEM. Reference [23] has utilized the PEM to provide the scenarios of stochastic formulation of security constrained unit commitment problem. Authors of [23] have replaced the Monte Carlo scenario generation method with PEM to reduce the computational burden of program. Additionally, authors of [24] used the PEM for reduction of consumed computational time of security constrained unit commitment problem beside the bender's decomposition. The used method breaks its large scale probabilistic problem to some deterministic ones by application of its proposed approach. Probabilistic analysis of renewable generation integrated distribution network using LHS has been presented in [25]. This study used LHS to overview the over voltage problem of renewable integrated distribution network considering uncertainties.

In despite of high computational speed of PEM and LHS, decreasing the accuracy is the main disadvantage of these approaches. In the other hand, increasing the results accuracy will rise the computational time. Therefore, a new method of probabilistic power flow has been studied in this paper, which can decrease the obtained results error with holding the computational time in competitive condition with previous methods. Moreover, the both parameters of time and accuracy are so important in the probabilistic methods, which are presented to investigate the recent renewable integrated distribution networks. Significance of time rises up from the functions of distribution networks, which need quickness of analysis such as dynamic reconfiguration. The methods, which require the high computational time for handling the uncertainties will not be applicable to such swift functions, practically. On the other hand, the results accuracy cannot be sacrificed for rapidness, entirely. The rapid but non accurate methods may cause the wrong decisions which damage the system. With regard to this point that the different problems of distribution networks require different