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Real time probabilistic power system state estimation

Morteza Aien [a,b,*], Masoud Rashidinejad [a,c], Sajjad Kouhi [d], Mahmud Fotuhi-Firuzabad [e], Sajjad Najafi Ravadanegh [d]

[a] Energy & Industry Commission of Kerman Chamber of Commerce, Industry, Mines & Agriculture, Kerman, Iran
[b] Energy Department, Graduate University of Advanced Technology, Kerman, Iran
[c] Electrical Engineering Department, Shahid Bahonar University of Kerman, Kerman, Iran
[d] Smart Distribution Grid Research Lab., Electrical Engineering Department, Azarbaijan Shahid Madani University, Tabriz, Iran
[e] Center of Excellence in Power System Management & Control (CEPSMC), Department of Electrical Engineering, Sharif University of Technology, Tehran, Iran

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ABSTRACT

Smartening of contemporaneous power delivery systems in conjunction with the increased penetration of renewable energies (REs), change the way to energize consumers who are willing to maximize their utility from energy consumption. However, there is a high degree of uncertainty in the electricity markets of such systems. Moreover, the unprecedented ascending penetration of distributed energy resources (DERs) mainly harvesting REs is a direct consequence of environmentally friendly concerns. This type of energy resources brings about more uncertainties into power system operation resulting in, necessitates probabilistic analysis of the system performance. In the smarter power markets, encountered the restructuring and deregulation, the online studies of system performance is of huge interest. This paper proposes a new methodology for real time state estimation, e.g. energy pricing by probabilistic optimal power flow (P-OPF) studies using the concept of hybrid artificial neural networks (ANN) and differential evolutionary (DE) method. In order to examine the effectiveness and applicability of the proposed method, two case studies are conducted and the obtained results are compared against those of Monte Carlo simulation (MCS) technique. Comparison of the results reveals the impressiveness of the method regards to both accuracy and execution time criteria.

Introduction

Uninterrupted variations of the energy consumption together with the integration of a significant amount of renewable energies (REs) such as wind and solar into the power networks bring about crucial operational challenges which stem from their inherent uncertainties. Real time pricing (RTP) is an effective mechanism used to manage the smart grids. If real time tariff of electricity is available in any time interval, consumers can react to this control signal and manage their energy costs. Optimal power flow (OPF) computation which can determine energy price at the system nodes, is one of the major requirements in power system planning and operation. Bare in mind that in such a highly uncertain and complex system, a deterministic OPF cannot reveal the state of system accurately; therefore, probabilistic studies are of significant importance. Deterministic OPF study requires specific values for all input variables such as loads, generation, and network conditions. In practice, modern power systems contain intermittent and variable energy resources like REs and therefore, the OPF uncertainty in such systems is not a minor subject, moreover, its real time application is another obligation. Performing P-OPF study helps the system planning engineers in making judgments concerning new investments by providing a better sense of future system conditions.

Generally, the term smart grid implies a fully automated electric power grid, controlling and optimizing operation of all its mutually connected segments, in order to warrant efficient operations of all energy generation, transmission and distribution facilities [1,2]. Note that the smart grids exhibits particular encouraging characteristics, e.g. demand side management (DSM) [3] and vehicle to grid (V2G) systems [4,5] among the rest. These capabilities yield notable benefits, e.g. enabling infrastructures for integrating large amounts of REs and installing distributed generation [6], new energy services and energy efficiency improvements [7]. Real time pricing of electricity in presence of different kind of uncertainties is of the major requirements for smart grid operation according to which electricity prices change frequently to represent variations in the cost of energy delivered [8]. Hence, this work mostly focuses on this issue and attempts to propose an appropriate technique to resolve this concern.

* Corresponding author at: Energy & Industry Commission of Kerman Chamber of Commerce, Industry, Mines & Agriculture, Kerman, 7619653498, Iran. Tel./fax: +98 341 2458394.

E-mail address: morteza_aien@yahoo.com (M. Aien).

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Nomenclature

D	index of load
G	index of generation
C_w	weibull scale parameter (m/s)
K_w	weibull shape parameter
NG	population size of DE
$P^i_{\max}$	maximum allowable limit of active power generated by unit i (p.u.)
$P^i_{\min}$	minimum allowable limit of active power generated by unit i (p.u.)
P^i_{net}	net of active power injection at bus i (p.u.)
$\mathbf{P_D}$	vector of loads active power (p.u.)
$\mathbf{P_G}$	vector of generators active power (p.u.)
P_r	WTG rated power (p.u.)
$\mathbf{P}_{wind}$	vector of wind farms power generation (p.u.)
P_{WTG}	WTG output power (p.u.)
$\mathbf{Q_D}$	vector of load reactive power (p.u.)
$\mathbf{Q_G}$	vector of generators reactive power (p.u.)
$\mathbf{Q}_{wind}$	vector of wind farms reactive power consumption/generation (p.u.)
$Q^i_{\max}$	maximum allowable limit of reactive power generation by unit i (p.u.)
$Q^i_{\min}$	minimum allowable limit of reactive power generation by unit i (p.u.)
Q^i_{net}	net of reactive power injection at bus i (p.u.)
S^{ij}	the line power flow between buses i and j (p.u.)
$S^{ij}_{\max}$	maximum allowable limit of line power flow between buses i, j (p.u.)
TC	total operation cost of the power system ($)
v	wind speed (m/s)
$\mathbf{V}$	vector of bus voltage magnitude (p.u.)
$V^i_{\max}$	maximum allowable limit of voltage at bus i (p.u.)
$V^i_{\min}$	minimum allowable limit of voltage at bus i (p.u.)
v_i	wind turbine cut- in speed (m/s)
v_o	wind turbine cut- out speed (m/s)
v_r	wind turbine rated speed (m/s)
$\mathbf{X}$	vector of uncertain input variables
$X_{best,g}$	best individual at generation g of DE
$X_{i,g}$	the ith individual at generation g of DE
$X_{r,g}$	random individual at generation g of DE
Y_{ij}	admittance between buses i, j (p.u.)
$\mathbf{Y}$	vector of uncertain output variables
μ	mean value of normal distribution
σ	standard deviation of normal distribution
δ	vector of bus voltage angles (rad)
δ_i	voltage angle at bus i (rad)
θ_{ij}	angle of Y_{ij} (rad)

Beginning with the uncertainty, to comprehend the engineering system uncertainties, probabilistic approaches have been used since the early seventies [9,10]. As yet, many probabilistic methods have been developed to study the uncertainty associated with engineering systems. These methods generally can be classified into two categories: simulation and analytical methods. Monte Carlo simulation (MCS) is the widely used simulation method. MCS provides more accurate results but its execution might be extremely time-demanding, which degrades its appeal in real time applications. In order to reduce the computational burden, analytical methods were proposed. The summary of the reviewed literature is as follows. The problem of economic dispatch was considered as a probabilistic problem in [11], where the authors used Gram–Charlier series to represent the probability density function (PDF) of the system uncertain loads. Based on the same Gram–Charlier series technique, a more general approach to account the uncertainties associated with all OPF variables was proposed in [12]. The first-order second-moment method (FOSMM) is found on the basis of the first order Taylor series expansion [12]. The fuzzy theory was used in [13] to consider the load uncertainty in the OPF problem. The MCS method was used in [14] to analyze the OPF under the uncertainty in the forecasted load. In [15,16], the authors developed a new approach in probabilistic studies based on the point estimation method (PEM). The two point estimation method (2PEM) was proposed to P-OPF study in [17], which can obtain the results with an acceptable level of accuracy.

The main advantage of the analytical methods mentioned above is to avoid the cumbersome computer simulations. In contrast, these techniques impose more assumptions and complex mathematical algorithms [18].

For some analytical methods such as 2PEM, the execution time is either proportional or exponential with respect to the number of uncertain variables. This can diminish the superiority of these methods against simulation ones when the system dimensions become larger and larger. So, their usage in real time applications is impractical in these systems. None of the currently used methods can generalize its solutions to new conditions. This indicates that under any new conditions, the problem must be solved again resulting in a very time consuming procedure. To overcome such disadvantages, new analytical methods for probabilistic nonlinear systems are exceedingly necessary, which must have the following properties:

1. An acceptable level of accuracy.
2. Reasonable execution time which is not strongly dependent on the number of uncertain variables.
3. Easy to implement.
4. Capable of adaptation with the new conditions.
5. Applicable to real time applications.

These requirements can be achieved using the methods based on intelligence system such as the artificial neural networks (ANN) that essentially simulate the human brain behavior. ANN has been frequently used in recent years in different power system applications such as load forecasting [19,20], electricity price forecasting [21], wind speed forecasting [22], and state estimation in distribution system [23]. Note that the state estimation under the uncertainty in distribution systems may be more difficult because of their radial architecture, less observability, and low bulk effect, especially at the LV level.

However, based on the authors' best knowledge, there is no reported work about online P-OPF studies using the ANN and this illustrates the novelty of this work. The main contribution of this paper is to develop a new approach for real time energy pricing by performing online P-OPF studies using the concept of ANN. The proposed method can overcome drawbacks associated with the currently used probabilistic methods, from the simulation to the analytical approaches, and opens a new horizon in this context. The developed approach is online, has the adaptation capability and a high degree of accuracy, which will be shown in the following. At commence, the proposed method is introduced; thereafter, it is implemented in the online power system P-OPF study taking into account the uncertainties associated with the forecasted load and wind power generation. In the following, the proposed method is applied to a 6-bus and 30-bus test systems and then, the obtained results are compared with the MCS results with regards to both accuracy and execution time.