# An Efficient Probabilistic Assessment Method for Electricity Market Risk Management

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***Abstract*—Managing electricity market risks is crucial for market participants. For electricity price risk management, expectation and standard deviation of price, along with possible occurrence of price spike, need to be assessed in order to support further risk control. In this paper, a hybrid probabilistic assessment method based on adaptive importance sampling (AIS) and sequential importance sampling (SIS) is developed. Improvements on AIS and SIS make the method better suit electricity market problems. Case studies are conducted on an equivalent Australian National Electricity Market (NEM) system. Uncertainties considered include system load, renewable energy output, generator bidding strategy, and outage rate. The proposed method provides much faster estimation of both normal price and price spike probability, meanwhile achieving comparable accuracy as Monte Carlo (MC) simulation results. Sensitivity of its estimation efficiency against different load level is also analyzed, which shows the robustness of the proposed method.**

***Index Terms*—Adaptive importance sampling, electricity market, price estimation, price spike probability, risk assessment, sequential importance sampling.**

## I. Introduction

THE POWER industry is full of uncertainties. In addition to the uncertainties in the power system, such as load, precipitation, line outage, unit outage, etc., deregulation of the power system brings more uncertainties. Bidding strategies of generation companies (GenCos) are typical uncertainties in electricity market studies, which at least include reported price and quantity. More recently, the promotion of large-scale renewable energy and the implementation of Emission Trading Scheme (ETS) or carbon tax have introduced uncertainties like renewable energy output and emission price. All these uncertainties could cause the electricity price to fluctuate violently, bringing operational and planning risk for electricity market participants.

Managing electricity price risk is crucial for market participants. Risk management at least includes two aspects: risk assessment and risk control [1]. Reliable and efficient assessment method is the basis for risk control.

For LMP-based electricity markets, P-OPF has been adopted to estimate market price. These probabilistic methods can be roughly divided into simulation method and analytical method. Typical simulation method like Monte Carlo (MC) simulation uses random generated samples to carry on crude estimation task, which is reliable but computationally demanding; typical analytical method such as Cumulants Method (CM) [2], [3] uses the concept of a cumulant to conduct an estimation task, which is computationally efficient, but more assumptions and complicated mathematical derivation are needed. two-point estimate method (2PEM) [4], [5] is more like a combination of simulation method and analytical method. By taking two deterministic points of each uncertain variable (which are calculated based on Taylor series expansion), 2PEM runs deterministic OPF twice for each uncertain variable. As stated in [4], the 2PEM provides satisfactory estimation of mean values; however, the estimation accuracy for standard deviations is less satisfactory, especially when the number of variables or their dispersion is large.

Importance sampling (IS) method is a variance reduction simulation method that uses biased probability distribution to focus on the regions of "importance". Sometimes the important regions are not so obvious or unknown; thus adaptive importance sampling (AIS) method is developed to "learn" about the important regions in an adaptive way. Sequential importance sampling (SIS) method [6] is an IS method whose fundamental ideas is a sequential buildup of proposal distributions, which is especially useful for high-dimensional problems. Various IS methods have been used in statistical physics [7], communication and detection [8], and many other rare event simulations. In power system, IS has been adopted for reliability evaluation [9], [10]. However, little work has been done in the area of the electricity market.

Simulation methods for probabilistic analysis are usually simple and easy to use, which do not need many assumptions and can avoid complicated mathematical derivation. At present, MC simulation is still the first choice to carry out probabilistic analysis for commercial electricity market simulation software.

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Nevertheless, more efficient simulation methods are needed to save computation resources, or for online application.

AIS and SIS methods are elaborated MC methods with much higher efficiency, which can find the important regions in the state space, saving computation resources. In this paper, an efficient probabilistic assessment method based on AIS and SIS is proposed. Basic ideas of this hybrid method include: decomposition of uncertain variables based on the "STATE-ACTION" criteria; the definition of importance and the construction of importance matrix; sequential importance sampling of the decomposed variables; adaptive update of importance; and estimation using properly weighted samples.

The improvements on generic AIS and SIS methods make the proposed method better suit problems in the electricity market. Case studies are carried out on an equivalent Australian National Electricity Market (NEM) system. Uncertain variables taken into account include system load, renewable energy output, unit bidding strategy, and unit outage rate. The number of uncertain variables that have been taken into consideration exceeds 40 in each case study. With much less computation time than MC simulation, the proposed method can provide reliable and efficient estimation results. To the best of the authors' knowledge, this is the first work to adopt AIS or SIS method in electricity market risk management.

The remainder of this paper is organized as follows: basic ideas of AIS method and SIS method are introduced in Section II. Basic ideas and computation framework of the proposed method are introduced in Sections III and IV. Case studies on an equivalent Australian NEM system are introduced in Section V. The results have proven the feasibility, efficiency, and robustness of the proposed method. Finally, conclusions are made in Section VI.

## II. Adaptive Importance Sampling and Sequential Importance Sampling

### A. Monte Carlo (MC) Simulation

For target function $h(x)$, where $x$ is stochastic (could be multi-dimensional) variable and $x \sim \pi(x)$.

Monte Carlo simulation will draw random samples $x_1, x_2, \ldots x_n$ according to $\pi(x)$, and estimate $h(x)$ with

$$\mu\{h(x)\} = E_\pi\{h(x)\} = \frac{1}{N}\sum_{i=1}^{N} h(x_i)$$
$$\sigma\{h(x)\} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\{h(x_i) - E_\pi\{h(x)\}\}^2}. \quad (1)$$

### B. Adaptive Importance Sampling (AIS)

Some regions of the state space of stochastic variables will contribute more to the estimation result than others. If those "important" regions are emphasized with a biased distribution (usually called "proposal distribution"), rather than the original distribution (usually called "target distribution"), the estimation efficiency will be greatly improved.

The basic methodology of importance sampling is to use a proposal distribution $g(x)$ which "encourages" sampling from important regions. Expectation of the target function $h(x)$ is

$$\begin{aligned}\mu\{h(x)\} &= E_\pi\{h(x)\}\\ &= E_g\{h(x)\pi(x)/g(x)\}\\ &= E_g\{h(x)w(x)\}\end{aligned} \quad (2)$$
$$E_\pi\{h^2(x)\} = E_g\{h^2(x)w(x)\} \quad (3)$$

where $w(x) = \pi(x)/g(x)$ is the weight of $h(x)$. Standard deviation of $h(x)$ is

$$\sigma\{h(x)\} = \sqrt{E_\pi\{h^2(x)\} - E_\pi\{h(x)\}^2}. \quad (4)$$

A well-chosen proposal distribution $g(x)$ will greatly enhance the computation efficiency. However, an inappropriate proposal distribution could make the IS method less efficient than the MC method.

It is always preferable to "learn" an appropriate proposal distribution with MC sampling. A simple way of achieving this is to start with a trial proposal distribution, say $g_0(x)$. With repeated MC simulation, a new trail distribution can be constructed based on the weighted MC samples. This can be iterated until certain termination criterion is satisfied [11].

This procedure described above, which updates the proposal distribution adaptively, is the AIS method.

### C. Sequential Importance Sampling (SIS)

SIS is a useful IS strategy that builds up the proposal distribution sequentially. It usually requires a decomposition process. Suppose the stochastic variable set $\mathbf{x}$ can be decomposed to $\mathbf{x} = (\mathbf{x}_1, \ldots, \mathbf{x}_d)$, where $\mathbf{x}_i$ may be multidimensional. The proposal distribution of $\mathbf{x}$ can be constructed as

$$g(\mathbf{x}) = g_1(\mathbf{x}_1)g_2(\mathbf{x}_2|\mathbf{x}_1)\ldots g_d(\mathbf{x}_d|\mathbf{x}_1, \cdots, \mathbf{x}_{d-1}). \quad (5)$$

Suppose $\pi(\mathbf{x})$ can be rewritten in the form

$$\pi(\mathbf{x}) = \pi_1(\mathbf{x}_1)\pi_2(\mathbf{x}_2|\mathbf{x}_1)\ldots \pi_d(\mathbf{x}_d|\mathbf{x}_1, \cdots, \mathbf{x}_{d-1}). \quad (6)$$

Thus, the weight can be calculated as

$$w(\mathbf{x}) = \frac{\pi(\mathbf{x})}{g(\mathbf{x})} = \frac{\pi_1(\mathbf{x}_1)\pi_2(\mathbf{x}_2|\mathbf{x}_1)\ldots\pi_d(\mathbf{x}_d|\mathbf{x}_1,\ldots,\mathbf{x}_{d-1})}{g_1(\mathbf{x}_1)g_2(\mathbf{x}_2|\mathbf{x}_1)\ldots g_d(\mathbf{x}_d|\mathbf{x}_1,\ldots,\mathbf{x}_{d-1})}. \quad (7)$$

The estimation method of SIS is the same with normal IS methods. SIS is especially suitable for high-dimension problems using this sequential buildup of proposal distributions.

## III. Ideas of the Proposed Method

Based on the practical situation of electricity market, a hybrid method is elaborated, which is a mixture of AIS and SIS methods. In this section, the basic ideas will be introduced.

### A. Criterion of Decomposition

The various participants in the electricity market, such as GenCos, LSE, customers, etc., make everyday decisions based on the market information published by PX or ISO. This process