Jurnal Teknologi

Full paper

Review of Available Transfer Capability Determination with Grid Connected Hybrid Wind System using Probabilistic Collocation Method

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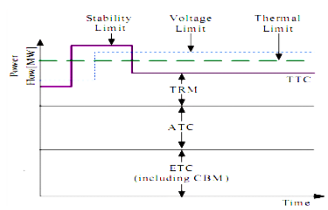
Article history

Received : 15 August 2014
Received in revised form :
15 October 2014
Accepted :15 November 2014

Graphical abstract



Abstract

Any distribution system with large integration of renewable energy based dispersed generations exposed to several difficulties clearly appeared while evaluating complex large-scale system Available Transfer Capability (ATC), where it is considered as one of the indices reflecting levels of reliability and security for power systems. This paper presents a review of ATC determination of the hybrid wind connected system using Probabilistic Collocation Method (PCM) under transient stability, voltage constraints. Applications of PCM technique in several electrical fields of power system transient-state evaluation are also debated, compared with Monte Carlo method. The first results shows the vast time saving obtained using PCM, with satisfied accuracy. The main goal of the review is to exploring different available usages of PCM technique and their corresponding suitable so that a reasonably precise and effective PCM algorithm can be determined for the concerned system, the relevant theory is outlined here, and unpretentious examples are applied to illustrate the applicability computation of ATC value implementing PCM method, as well as an example with a more credible power system, are obtainable. The feasibility of the suggested method would be validating through in the IEEE-24 RTS bus system.

Keywords: ATC computation; Probabilistic Collocation Method (PCM); transient stability; dynamic simulation; uncertainty analysis

■1.0 INTRODUCTION

Reliability is one of the most vivacious desires in the operation of Grid Connected Hybrid Wind Power Systems (GCHWPS), in recent years; environmental concerns on global warming and local pollution have steered many countries and regions to indorse renewable energy sources as a means of meeting emissions reduction targets.

Wind Generation Technologies (WGT) are presently becoming increasingly grown, and the wind power is a fast growing and most promising one among all renewable energies. According to the statistical data of World Wind Energy Association (WWEA), worldwide installed capacity of all wind turbines reaches159, 213 MW in the end of 2010s, out of which 38, 312 MW were added in 2010s, total wind bulk of 200,000 Megawatt will be overdid within the year 2010s, with rate of 31.7 % growth .Based on accelerated development and further improved policies predictions and sees a global capacity of 1,900,000 Megawatt as conceivable by the year 2020s [1].

Stability also is an important factor of power system security, which is closely dependent on the ATC calculations value, in fact, load model parameters, in particular, are often a source of perceivable error. The majority of past studies into power system uncertainties have focused primarily on reliability [2]. The deterministic approach is not sufficient for the analysis of modern power systems, and the results from Deterministic Load Flow (DLF) may give an unrealistic assessment of the system performance. In order to take the uncertainties, e.g. inform of e.g. the outage rate of generators, the modification of network configurations and the variation of load demands. Furthermore, modern power systems with integration of DG units, such as WTs and photovoltaic systems, introduce additional power fluctuations into the system due to their uncontrollable prime sources. The PLF was first proposed in 1974 and has been further developed and applied into power system normal operation, short-term/long-term planning as well as other areas[3][4][5]. The PLF requires inputs with Probabilistic Density Function (PDF) or Cumulative Distribution Function (CDF) to obtain system states and power flows in terms of PDF or CDF, so that the system uncertainties can be included and reflected in the outcome. The PLF can be solved numerically, i.e. using a MC method, or analytically, e.g. using a convolution method, or a combination of them [6][7][8]. The main concern about the MC method is the need of large number of simulations, which is very time-consuming; whereas the main concerns about the analytical approach are the complicated mathematical computation and the accuracy due to different approximations.

The parameters of many dynamic models are quite uncertain, it is difficult to obtain certainty limits by employing conventional statistics, also in case of high penetration of renewable energy on power system a problem may occur in term of significant impact on the value of Available Transfer Capacity (ATC) in the power systems, NERC defined ATC as "a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses", derived in Equation (1) as:

$$ATC = TTC - TRM - CBM - ETC \quad (1)$$

Where TTC is the Total Transfer Capability, TRM is the Transmission Reliability Margin, CBM is the Capacity Benefit Margin, ETC is the Existing Transmission Commitments [9], limitations incorporated ATC related parameters as illustrated in Figure 1.

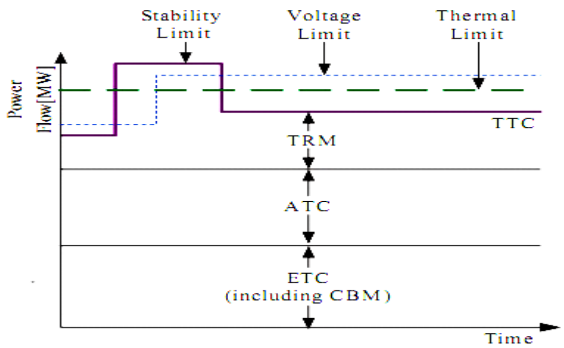


Figure 1 1limitations incorporated ATC related parameters

Several uncertainties correlating with the parameters and forecasting quantities used in the ATC evaluation, several techniques are used scarcity to accuracy and speed. This paper presents a review of ATC determination involving diversity uncertainties with dynamic stability constrained using Probabilistic Collocation Method (PCM) technique, where vast saving time and facilitates towards ATC stability online studies. The Monte Carlo method is widely used in stochastic modelling, and is independent of the number of random dimensions. However, if the process encompassed within the MC approach is complex, the full study can require vast computational effort and time, resigning the analysis to the offline or planning stage [16]. Furthermore, for complex systems a great number of simulations may be required in order to be confident that full system variation in the parameters is captured.

It is necessary to construct a rational ATC model and effectual calculation method for power systems containing uncertainties. Based on that, it is expected that PCM can be a method to determine ATC with the uncertainty voltage stability. The Probabilistic Collocation Method (PCM) by Tatang in [11], is a technique significantly reduce the number of simulations that are required and still accurately produce the probability distributions for system parameters, but was first introduced as a tool for dynamic power system studies in [12], is the method has been applied in several field [1], and later for investigating the effects of load models involving very few uncertain parameters (no more than two) in [13] [14].

The main purpose of applying PCM method is to approximates the system response as a polynomial function of the uncertain parameters, replacing the computationally intensive study with a simple deterministic algorithm, also it provides two clear benefits essentially suitable to the application of power system uncertainty studies. Firstly, the method is designed to provide a statistical distribution for the system output, this is of great value when considering statistical uncertainty in future operating points and trying to calculate risk indices with system uncertainty likely to increase, methods that present the probabilistic nature of the network response are vital in ensuring accurate system representation.

Secondly, the method affords significant savings with respect to the number of full system studies that are required [15], this leads to a decline in computational time when performing these types of analyses and could permit the incorporation of uncertainty into online studies which assist a move towards a greater use of probabilistic studies in power systems analysis.

It is necessary to construct a rational ATC model and effectual calculation method for power systems containing with wind generation. Traditional approaches to uncertainty analysis such as Monte Carlo, even with structured sampling and other techniques to improve its efficiency are not feasible for application to complex change models. Based on that, it is expected that PCM can be a method to determine ATC with the uncertainty voltage stability and solution for the above problem.

Conventional Monte Carlo method suggested to simulate collected uncertainties output responses, Expected numerical simulation results will be simulated using the IEEE 24-bus system, validation step would be performing via a comparative analysis of the results with the proper outputs and with the traditional Monte Carlo model, initial results shows feasible and effective. The impact of wind turbines connected to power system on ATC should be analysed with help of MATLAB calculation technique and NEPLAN analysis software. The suggested model will developed for National Electric Power Grid, proposed integrated method would be implemented.

The results provide a great opportunity to have a clear evaluation of hybrid system ability. Rest of this paper will be organized as follows; Second section will give a brief review on Probabilistic Method; Third section will introduce a review of previous PCM method applications. PCM theoretical explanation, verifies the applicability of ATC computation using proposed method, in section four. Analysis the effects of uncertain parameters on system transient stability and dynamic simulation applied on IEEE 24-bus discussed in section five.

2.0 PROBABILISTIC METHODS

Because of the necessity of considering several limitations in ATC computations, different optimization methods are used; most important of them are voltage, thermal and satiability limitations which are considered in most of ATC computations.

ATC calculation are tremendously time consuming and cannot be executed for online power systems. Therefore more efficient method which:

a) Can consider almost of constraints.
b) It is possible for predicting ATC by the effect of uncertainties.
c) It's computational time is low [16]. Generally, the influence of system uncertainties on the ATC has been assessed using probabilistic methods.

Yuan and his colleague introduced a novel algorithm by incorporates linear distribution factors and AC load flow sensitivity-based method in order to calculate ATC values efficiently and speedily considering line outages, distribution factors still unsatisfactory covered [17].

Kulyos Audomvongseree and Akihiko Yokoyamaa, propose a method by using probability density function (PDF) to provide an alternative choice for transmission providers (TPs) or ISOs, It seems a solution to decrease error, but still time consumed [18].

Shaaban and his colleagues, with steady-state security constraints using Benders decomposition method, the results improved rather other technique mentioned [19].

Leite da Silva *et al*., proposed a new methodology to determine the best points in the system, in order to maximize the ATC, without violating a pre-established reliability level. In the process, the ATC probability density function is determined considering uncertainties from equipment un-availabilities. Proposed algorithm uses Monte Carlo simulation, this means time consumed needed [20].

The most important methods used are artificial, Cubic Spline, Stochastic programming and Monte Carlo methods. Deqiang G, *et al.*, using new method called Min-Max transfers capabilities interfaces, because of too much data needed and calculations cons of this method [21]. The Monte Carlo method is a known method, used to obtain the solution of the stochastic power flow problem, often characterized by a large computation time. Nonetheless, the Monte Carlo has been used in many general engineering applications [22], [23]. To enhance disadvantages of MC, a stochastic-algebraic method employed for the first time by assuming the system is linear with applying just thermal limitation [24]. Stochastic-algebraic method with voltage and thermal constraints, improved by considering two uncertainties, bus loading and transmission element status in [25]. To deal with uncertainties, several techniques aims to define the points to evaluate the problem and calculate the statistics of the outputs using different methods as: methods as:

1. Multi-point Criteria:
   - Select regularly spread values within the range.
   - No statistical criteria is used.
2. Monte-Carlo (MC) method:
   - Statistical definition of the set of samples.
   - Values defined according the Probability Density Function (PDF).
3. Latin Hypercube method:
   - Statistical definition based on MC.
   - Improves the variance convergence.
   - Based on Latin square criteria.
4. Probabilistic collocation method:
   - Based on collocation techniques.
   - Can be considered a multi-point method which account with probabilistic information [13].

2.1 ATC Wind Generation Computations

The impact of wind power generation on the ATC value explained by Luis Luna *et al.*, and the use of linear approximations to update for estimating the capacity of transmission is widespread [16].

References [17] proposed the improved PQ model, and presented RX model for modelling of wind farms in load flow analysis, and applied the impedance containing slip to be the equivalent of wind turbines, which seems effective approach for final approximation of ATC value.

Karki R, Po Hu, Billinton, confirmed that sequential Monte Carlo simulation or a multistate wind farm representation approach is often used to evaluate wind sources integration reliability, and presents a simplified method for reliability evaluation of power systems with wind power. The development of a common wind speed model applicable to multiple wind farm locations to gain high level reliable system [18].

Yajing Gao, *et al*. Presents a new ATC computation model with offshore wind farms connecting to the grid via VSC- HVDC is proposed, in this model the characteristics of offshore wind farms and VSC-HVDC control is considered, CPF algorithm is presented to solve this model and then the ATC value of power system can be gained [13].

ATC computation related to dynamic voltage stability constrained, is one of the significant issues must be taken in account in large GCHWPS, Paensuwan & Yokoyama present a method suitable to exam such impacts on TTC, using Monte Carlo simulation in [14].

Reference construct static security based smoothing ATC model by using the pointwise maximum function. Along the work, derives the power flow model including wind turbines where the slip is as a new state variable, then, by integrating power flow model combining with wind turbines and conventional static security constraints, a new semismooth ATC model is constructed based on the so-called pointwise maximum function. Various methods can be utilized to evaluate transmission transfer capability, comparison between calculations techniques used over decades illustrating in Table 1.

Table 1 Comparison between calculations techniques used over decades [14]

Constraints & Uncertainties	Methods				
	Stochastic Programming	Monte Carlo	Cubic Spline	Artificial Methods	Linear Sensitivity
V	✓	✓	✓	✓	✓
P_{max}	✓	✓	✓	✓	✓
P_g		✓		✓	
Q_g		✓		✓	
P_l		✓		✓	
V. Stability	✓				
Component Outage	✓	✓	✓	✓	
Load Variation	✓	✓			✓

3.0 PCM TECHNIQUE APPLICATIONS

Lesieutre, B.C. and J. Hockenberry, was the first introduce treating uncertainty analysis of power system simulations and ATC calculations using the probabilistic collocation method [15]. Yan Wan *et al.,* present realistic comparison between PCM technique and Monte Carlo in uncertainty evaluation through mapping identification in intensive dynamic simulations testing just one or two uncertainties [28]. Webster *et al.*, presents the probabilistic collocation method as a computationally efficient method for performing uncertainty analysis on large complex models such as those used in global climate change research [16]. Ce Zheng, Mladen Kezunovic preform uncertainty analysis related impact of wind generation variation, on the small disturbance voltage stability, using new method PCM, comparison the results with conventional methods to realize the accuracy, saving time consumed computations [28]. Preece. R, Milan apply PCM Method to model operational uncertainties in small disturbance power system studies included distributed generation and renewable energy sources, the significant computational time savings achieved could allow such analyses to be performed in online scenarios [29]. Hockenberry, Lesieutre in 2004 was first introduce of PCM method studding uncertainties of dynamic simulation of power system models, using only a handful of simulations, The larger system example demonstrates the time savings and enabling aspect of PCM in conjunction with the associated methods. The results presented here would take months to gather using other standard methods [6].

4.0 PROBABILISTIC COLLOCATION METHOD

To deal with uncertainties, several techniques are used in conjunction with a deterministic approach for ATC evaluation. For instance, an optimal power flow method in conjunction with Monte-Carlo simulations was proposed to evaluate ATC and associated risks [14], [6]. The basic idea of Probabilistic Collocation Method PCM is to approximate model response as polynomial function of the uncertain parameters, based on the Probability Density Functions (PDF) of the uncertain parameters [12]-[16]. As very few tools are available to analyse the parameter uncertainties in time-domain simulations, design of PCM approximation used for voltage stability analysis accessible in Figure 2.

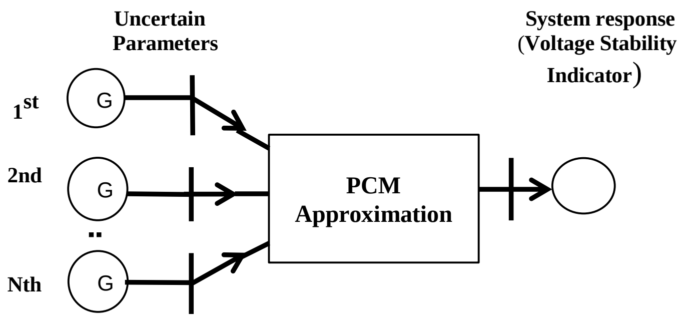


Figure 2 PCM approximation used for voltage stability analysis

The probabilistic collocation method (PCM) by Tatang, was developed mathematically to describe the system response in terms of uncertain parameters [5]. This method has been successfully applied to time-domain simulation studies in the area of global climate change [16]. Many recent studies are focussed on evaluating the advantages of PCM over other uncertainty analysis techniques in the time-domain analysis of power system load parameter uncertainties[7], [16]. Normally the uncertainty analysis is performed under one of the following situations:

(1) The relationship between the uncertain parameter and the output of interest is known analytically;

(2) The above relationship is unknown

A model of the “black box” needs to be approximated first. The PCM is designed to address the second situation. This approach allows the use of nonlinear models and evaluation of complicated output functions. It is particularly appealing because it requires a much smaller number of simulations to reach an accurate approximation which may take hours or days for the traditional techniques. The probabilistic collocation method (PCM) provides a computationally efficient approach to building an approximate relationship between random variables and outputs that depend upon those variables. In assessing the impact of parameter uncertainty, it is assumed that the parameters of interest satisfy given probability density functions f(λ) [17]. The desired outputs are obtained by running a simulation for each randomly chosen set of parameters. Any feature of the trajectory could be chosen as an output, for example the values of states at certain times, and/or the maximum voltage dip. This section provides an overview of PCM.

More complete details are presented in [6] In order to simplify notation, the discussion will assume a single uncertain parameter. The ideas extend to larger numbers of parameters, though with increased computations.

For a given probability density function f (λ), a set of orthonormal polynomials hi (λ) can be determined. The subscript *i* refers to the order of the polynomial, and orthogonally is defined in terms of the inner product

$$< hi(\lambda) \text{¸} hj(\lambda) > = \int f(\lambda) hi(\lambda) hj(\lambda) d\lambda \qquad (2)$$

Underlying PCM is the assumption that the uncertain parameter λ ¸ and the output of interest are related by a polynomial $g(\lambda)$ of order 2n–1. This is generally not strictly true, though such polynomial approximation is not unusual. Given this “true” relationship $\hat{g}(\lambda)$ between parameter and output, PCM determines

4.1 PCM with Multiple Inputs

To be general, let $x_1, x_2, \ldots, x_n$ be the uncertain parameters. Suppose a system is represented by a complex, high-ordered, or even “black-box” model. Its response in terms of the uncertain parameters is expressed as:

$$\hat{U} = P(x_1, x_2, \ldots, x_n) \qquad (3)$$

The objective of PCM is to find the following approximation of *U*:

$$\hat{U} = c_0 + \sum_{i=1}^{n}[C_{i1}\, p_{i1}(x_i) + C_{i2}p_{i2}(x_i) + \cdots + C_{im}p_{im}(x_i)] + \sum_{i=1}^{n} \cdot \sum_{\substack{j=1 \\ j\neq 1}}^{n} [C_k p_{i1}(x_i) p_{j1}(x_j)] \qquad (4)$$

where $\hat{U}$ is an approximation of U, *m* is the order of this polynomial model, $C_0, C_{i1}, \ldots, C_{im}, C_k$ are model coefficients, and $pi_1(xi), pi_2(xi), \ldots, pim(xi)$ are polynomial functions in terms of each uncertain parameter *xi*.

4.2 Solving for Polynomials

The need now to find the set of polynomials and coefficients listed in (3), the polynomials could be derived by deploying the concept of orthogonal polynomials:

$$\int_x p(x) H_i(x) H_j(x)\, dx = \begin{cases} 1, \text{if } i = j \\ . \\ 0, \text{if } i \neq j \end{cases} \qquad (6)$$

where *P(x)* is user-defined weighting function of *x, Hi(x) and Hj(x)* are orthogonal polynomials of *x* with the order of *i* and *j (i, j = 0, 1)* Equation (5) suggests that the inner product of any two orthogonal polynomials of different order is always zero.

4.3 Solving for Coefficients

As long as the polynomial functions in (3) are known, the model coefficients can be calculated by feeding different inputs into the system and recording corresponding system response. Suppose the system has ***n*** uncertain parameters, and we are using a PCM model with the order of *m*, the sets of inputs that are needed:

$$1 + n + m + \binom{n}{2} \quad (7)$$

Take the linear PCM model with single uncertain parameter *x* as an example, Equation (2) could be rewritten as:

$$\widehat{U} = C_0 + C_1 p_1(x) \quad (8)$$

what we need next is to feed the real system with two different values of parameter *x*, and substitute $\widehat{U}$ with the real system response *U* of each run. Thus the coefficients C_0 and C_1 in (6) could be solved.

In the above linear model example, the two different input values are also called collocation points. It should be noted that the selection of collocation points has significant impact on the accuracy of model approximation. In order to find a good approximation for the PCM model with smallest number of model runs, the Gaussian Quadrature Integration approach is deployed while selecting the collocation points, the points for the model runs from the roots of the next higher order orthogonal polynomial will be selected for each uncertain parameter.

This approach enables the collocation points spanning the high probability regions of their distribution and capturing as much of the behaviour of system response as possible. The whole idea of applying PCM in power system uncertainty analysis is demonstrated in Figure 3. Selected set of uncertain parameters is fed into the full dynamic model of a power system and corresponding output of interest is recorded. The relationship between uncertain parameters and system response is then approximated through PCM once sufficient tests are conducted [6]. More theoretical explanation related PCM for known and an unknown parameter probability distribution could be found in [28].

PCM can be easily implemented with any of the existing simulators such as CHEARS, CMG, ECLIPSE, IPARS, VIP, MODFLOW, MT3D, FEHM, and TOUGH2.

4.4 ATC Calculation using PCM Technique

The task of computing ATC subject to dynamic security constraints however is very challenging due to the nonlinear nature of interconnected power systems and the tremendous computation requirements for stability analysis of credible contingencies. The main idea of using PCM method for computation ATC value with uncertainties analysis and small disturbance voltage stability constrained is using orthogonal polynomial functions based on Gaussian quadrature equation of power flow model. Uncertainty analysis procedures PCM method calculating ATC has been illustrated in flow chart Figure 3.

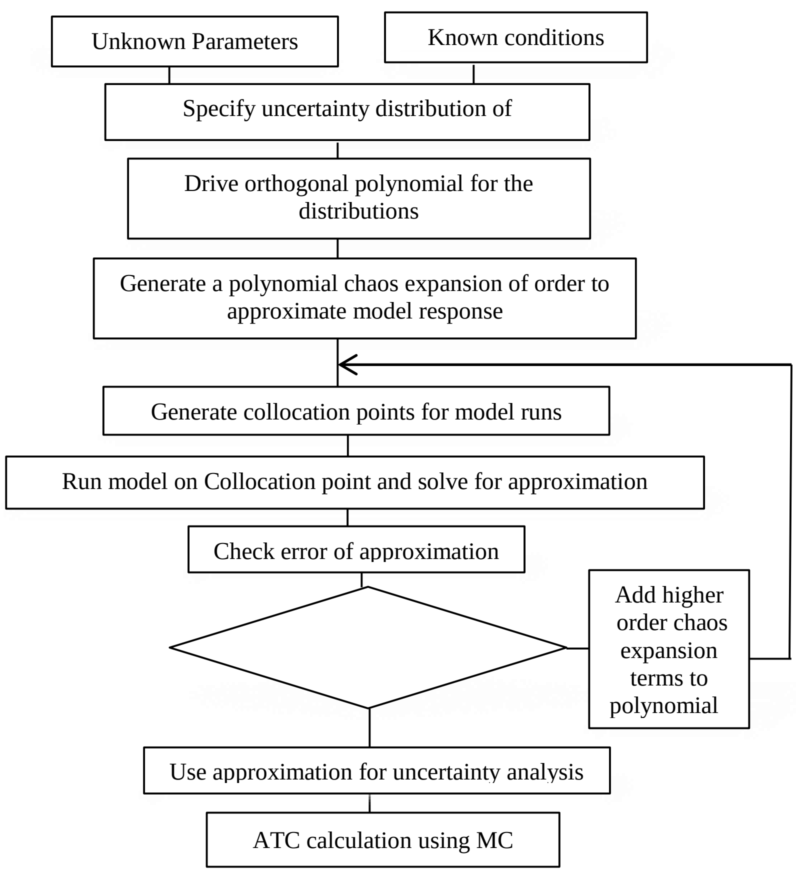
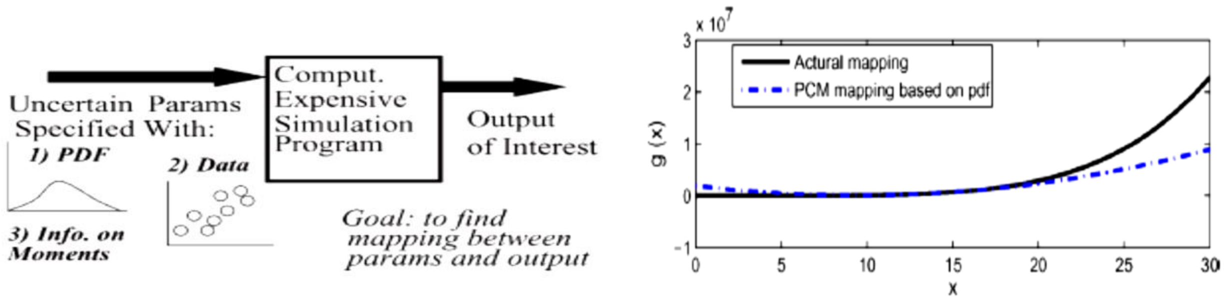


Figure 3 Flow chart of uncertainty analysis procedures PCM method calculating ATC

4.5 Mapping between Parameters and Output

PCM method works as Black Box, in case of computation ATC by, uncertain parameters specified as shown in Figure 4.where PDF represents the parameters related sensitivity factors. Data are variables represents changing of generation, changing of load, voltage constraints. To approximate all these with help of reduction method, output of interest used by help of traditional method as MC to get ATC value.



(a) (b)

Figure 4 (a) Mapping between parameters and output, (b) Comparison between actual and PCM mapping

■5.0 ANALYSIS THE EFFECTS OF UNCERTAIN PARAMETERS ON SYSTEM TRANSIENT STABILITY

The results of this topic are not fully ready, also because of submitting dead line. Discussed in section five as addendum.

■6.0 CONCLUSION

This paper proposed a PCM based method to propagate the uncertainty from the hybrid ATC computation system parameter in time domain. The advantages include (1) the computational cost is significantly lower than that of the classical MC method; and (2) the method can use taking in account more than uncertainty parameters. Still, this method has a drawback that the PCM method cannot approximate multimode distributions accurately even with very high order expansions. This may occur at certain uncertain parameter which usually unknown. Recently, the method of mixtures of polynomial chaos expansions is thought to be a proper way to converge quickly when the distribution of the model response is multimode. This may be applied to the uncertainty propagation as an improvement of the current method in the future work.In this paper, the issue of computation ATC constrained small disturbance voltage stability in GCHWPS area has been suggested as the area to be improved, because of necessity,

One of the main important factors related to improve results is saving time. Through preliminary results concerning load power flow illustrated, that PCM worked effectively. The probabilistic collocation method is introduced to perform the uncertainty analysis for wind generation. A classification of situations and routes must be taken in account. Derived from the wind turbine cut-in, cut-out and rated wind speed is required. The PCM is applicable for ATC small disturbance voltage stability analysis calculations.

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