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Methodology of risk analysis by Monte Carlo Method applied to power generation with renewable energy

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ABSTRACT

This paper presents a methodology that uses the Monte Carlo Method (MCM) to estimate the behavior of economic parameters which may help decision, considering the risk in project sustainability. In order to show how this methodology can be used, a Grid-Connected Photovoltaic System (GCPVS) of 1.575 kWp, located on the roof top of the laboratory building of the Grupo de Estudos e Desenvolvimento de Alternativas Energéticas – GEDAE, at the Universidade Federal do Pará – UFPA, Belém – Pará – Brazil, and operating since December 2007, is analyzed. This system was chosen because it was the first GCPVS installed in the Brazilian Amazon Region, being the first risk evaluation on using a renewable energy source connected to the grid in the Region. This work also presents a similar treatment for the case of a stand-alone photovoltaic system (SAPVS) installed in the remote Santo Antônio Village, municipality of Breves, Pará, Brazil, considering the risk of investment assumed by an investor in power generation projects with similar characteristics or using other renewable energy sources. The last case allows a better assessment for other important applications of renewable energy in the Amazon Region, where the demand for energy is growing, but is still costly and often not a priority in government actions.

1. Introduction

The sustainability of any power generation system is, in general, the target to be achieved. Many economic parameters are usually used to estimate the economic sustainability of a system in a deterministic manner, since it seems to be easy to define a project execution using a simple number.

The option for one or more economic indexes is connected to the fact that not only the investment return must be assured, but the risk in its execution should also be considered. The Net Present Value, *NPV*, which brings to the present the difference between incoming and outgoing cash flows during a project lifetime, and the Cost Benefit Risk Index, which shows the profit per unit capital invested during the project, are considered investment return indicators. The Internal Rate of Return, IRR, which represents the return rate which makes zero the *NPV* and the Payback Time, PT, that shows the necessary time to recover the investment costs, are used as risk indicators.

In order to obtain a precise value for *NPV*, which for its robustness and for presenting information about profit or loss by a simple economic value, is one of the most used indexes in investment analysis, other consistent informations are also necessary. In general, informations used to calculate *NPV* include some uncertainty. Deterministic methods that depend on these data assume a constant value for some indexes, like interest rate, inflation, cost of equipment used or energy produced, not considering changes in information along project lifetime.

Probabilistic methods for *NPV* calculation may include several parameters that vary along the time. Information processing results in a group of values for *NPV*, which, differently from the deterministic methods, show this index from probability distribution functions. In this case, the consideration of uncertainty of initial information gives a probabilistic scenario for the investor to make his decision. Monte Carlo Method [1–4] considers the uncertainty in independent variables' behavior using probability distribution

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functions in a model that presents as a result a probability distribution to show the occurrence possibility of a certain situation. Due to this feature, MCM can be applied to problems of many areas such as: engineering, medicine, finance, etc.

Considering its simplicity and the possibility of incorporating risk factors, associated to the simple integration with structured spreadsheets such as MSExcel, MCM was chosen to illustrate the risk analysis in power generation systems with renewable sources.

Risk and uncertainty are always present in economic evaluation of projects. Several economic parameters are used for this purpose. Some of them consider the value of money in a cash flow, such as: *NPV*, IRR and PT. Cash flow is derived from other factors as interest rate, value of energy produced or sold to the utility, and purchase cost of equipment, which may vary at the beginning or throughout the project. Each of the variations carries out its own uncertainty and, when considered together, they may increase the risk in the project evaluation.

A lot of ways to take into account the risk assessment of future cash flows are used in the evaluation of power generation systems with renewable sources, such as the analysis of scenarios [5,6] or sensitivity analysis [7–9]. The first takes into account, for example, three possible situations: the most likely scenario, which works out the situation of most probable occurrence of parameters that show some variation in project lifetime; the optimistic scenario, where the risk parameters, although less likely, are chosen to favor the economic index under analysis; the pessimistic scenario, where the risk parameters are unlikely and show a quite unfavorable condition to the index analyzed.

In the sensitivity analysis, the influence of each parameters of risk is determined at a time, what allows the verification of which parameter has the greatest influence in the index analyzed. Some software, such as Reno [10], RetScreen [11] and Homer [12], present the economic feasibility of power generation systems with renewable sources through sensitivity analysis. They do not allow, however, the evaluation of the risk in the system sustainability along its lifetime, since the probability of occurrence of all parameters which influence the risk is seen as the same in all simulations.

The MCM is a powerful alternative to the estimation of the risk of a project [13]. Risk analysis may not guarantee the complete success of a project, but it may analyze what the risk of taking a particular decision is. Then, while deterministic methods offer important informations about a project, but not taking account possible changes in parameters that influence its behavior, probabilistic methods associated to MCM may consider simultaneous variations in several parameters, in order to allow easy and quickly a complete analysis related to the sustainability of a project. A project, for example, may presents a positive *NPV* at the end of its lifetime, when analyzed by deterministic methods, what is not conclusive to take a decision of execute it. However, probabilistic methods may show how simultaneous changes in other parameters, as equipment cost, interest rate and inflation along lifetime, influence *NPV*, offering by probability distribution function, an open vision of *NPV* behavior, what may show the real risk on project execution.

2. Monte Carlo Method applied to risk analysis of power generation systems

MCM is a statistical sampling technique that operates with random components as input variables subject to uncertainties, and presents, after several iterations, a set of results in terms of probabilities [13].

The choice of probability distributions and their limits, and a good generator of random sequence of numbers that represent them, are very important in the MCM. Inappropriate choices may lead to mistaken decisions. At the same time, it is also important to define the number of iterations required for the convergence of the method. As the number of iterations increases, according to the Central Limit Theorem [1], the mean and the standard deviation of the samples tend to the average and the standard deviation of a normally distributed result [13].

MCM has several advantages as: it allows model correlation between different dependent variables; simple mathematics is involved; calculation of the distribution functions is performed by computer; availability of several commercial software; treatment of linear and nonlinear models from simple to complex ones without great difficulty; changes and tests in the model can be performed quickly and easily; working with several independent variables simultaneously, results in a probability distribution function for the output variable, helping the decision on accepting the risk of a particular action [1].

The methodology applied in this paper follows the steps presented in subsections 2.1–2.6.

2.1. Mathematical model

The model applied in this simulation takes the *NPV* as the parameter that will help the investor's decision making. Its achievement is made by net cash flow throughout the project lifetime. Eqs. (1)–(5) establish the mathematical formulation to obtain the *NPV* [7].

$$S = C_{gen} + C_{inv} + C_{inst} + C_{cc} + C_b - C_{sub} = C_{system} - C_{sub} \quad (1)$$

where

S – total initial costs
C_{gen} – power generation equipment costs (photovoltaic modules, wind turbines, fuel cells, etc.)
C_{inv} – inverter cost
C_{inst} – installation costs (engineering, structures, wires, connectors, equipment, transportation, etc.)
C_{cc} – possible charge controller cost
C_b – possible energy storage bank cost
C_{sub} – possible subsidy for investment costs
C_{system} – sum of initial costs without subsidy

The annual net cash flow after the project startup is given by Eq. (2).

$$Q_j = \left(\left(p_s \cdot E_{inj}\right) - \left(C_{O\&M}\right)\right)(1+g)^j - C_{fin} \quad (2)$$

where

Q_j – net cash flow at any year j after project startup, without equipment replacement costs
p_s – value of energy produced and sold to the grid or utility
E_{inj} – generated and injected energy into the grid or utility annually
$C_{O\&M}$ – annual cost with operation and maintenance
g – inflation rate
C_{fin} – financing cost

The total present value of equipment replacement costs, *PRV*, can be calculated from Eq. (3) using the acquisition value for equipment at year zero, *AVE*. The *PRV* takes into account the equipment initial costs plus the inflation in the period since it began to operate until its replacement. It must be calculated for each replaced equipment.