Analysis of Renewable Integrated DG Investment Planning Based on Emission Cost

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Abstract. The prospect of distributed power generation investment planning (DGIP) is particularly important in island networks due to multiple reasons such as energy security, emissions, and renewable energy integration goals. Against this background, this article proposes a consideration that includes various types of DGIP models including renewable energy. The planning process includes an economic analysis that takes into account emissions costs, reliability and other related cost components. In addition, the variability and uncertainty of model parameters for distributed generation comprehensive sensitivity analysis of the impact of investment decisions. The ultimate goal is to determine the parameters that have an important impact on the decision-making process and quantify their degree of impact. The results show that uncertainty has an important impact on DG investment decisions. In fact, the degree of impact varies depending on the parameters. However, in general, ignoring or not fully considering the uncertainty and variability in model parameters is a quantifiable cost. The analysis made in this article is the most relevant to determine the need for special attention in planning practice the model parameters are very useful.

Keywords: distributed generation, investment planning, distribution network system, uncertainty.

1. Introduction

Today, it is a global trend to integrate more distributed generation (DG) energy (especially renewable energy such as wind and solar energy) into the distribution network (DN) [1]. This is due to several technical economic and environmental factors the overall impact is driven [2]. The scale of distributed power sources integrated in power DN systems is steadily increasing [3]. Due to the emergence of emerging solutions such as active management of distribution networks, this trend may continue in the next few years, these solutions are expected to alleviate existing technical constraints and promote the smooth integration of distributed power sources [4]. The power demand covered by energy from distributed power sources (especially renewable energy sources) will gradually increase [5].
Therefore, this energy will play an important role in the power distribution system. However, it is worth noting that many distributed natural gas resources (such as renewable energy such as solar energy and wind energy) are intermittent in nature [6]. Therefore, they give the system brings significant operational variability and uncertainty [7]. In addition, several other parameters are affected by a high degree of uncertainty [8]. The combination of all these related issues complicates the operation and planning process. This effective methods and tools are inevitably required to achieve the optimal integration of distributed power sources [9]. Due to various reasons such as energy security, environmental and economic factors, and renewable integration goals, the prospect of distributed power generation investment planning (DGIP) is in the island network China is particularly relevant [10]. Therefore, the development of available energy sources (wind, solar, hydro, geothermal, etc.) is not only to meet the growing demand for electricity, but also to achieve environmental constraints and to set global or local settings through government initiatives of renewable energy (res) integration.

In this context, this paper proposes a DGIP model that considers various types of DG (including renewable energy). The planning process includes an economic analysis that takes into account emission costs, reliability, and other related cost conditions. In addition, this paper also analyzes the model parameters. A comprehensive sensitivity analysis of the impact of variability and uncertainty on DG investment decisions. The ultimate goal is to determine the parameters that significantly affect the decision-making process and quantify their degree of impact. For analysis, the DGIP problem is described as a multi-stage, multi-program optimization model that minimizes the expected net present value of investment, operation and maintenance, reliability, and emissions costs, while taking into account some technical and economic constraints. In addition, to ensure manageability, the entire problem is kept mixed integer linear programming (MILP) optimization. In general, the work of this paper focuses on the problems caused by the cost-effective integration of distributed power in island network systems, considering various variability and uncertainty.

2. Problem description

The focus of this paper is to study how sensitive distributed investment decisions are to a variety of uncertain parameters. This will determine the parameters that have the greatest impact on investment solutions in order to fully consider the variability and uncertainty of the most relevant parameters. The DGIP model is relevant. Ultimately, this helps ensure the best integration of DG in a network system. The DGIP problem is naturally dynamic because the solution must clearly provide the necessary information about when the DG investment is needed. Regarding the planning scope and decision-making stage, considering the dynamic nature of the problem, a more realistic approach may be to use multiple decision-making stages (i.e. (Multi-year decision framework) to formulate issues while taking into account all possible futures. However, to ensure maneuverability, the number of stages and scenarios is usually limited.

In this work, the DGIP problem is described as a multi-stage, multi-scenario optimization model within a given planning window (level). This modeling framework assumes that there are n possible future storylines (or scenarios), each probability of realization of source of uncertainty associated with each random storyline (or scenario) \( \rho_s \), associated.

2.1. Objective Equation

The DGIP model is described as a MILP optimization problem, and its objective function is to minimize the weighted sum of the net present value (NPV) of the three cost terms, as shown in formula (1). The first term in (1) is expressed in perpetuity the net present value of the DG investment cost under the assumption of the term of the investment plan, including conventional ress and various ress. In other words, “the investment cost is amortized annually over the entire life cycle of the installed DG”.

\[
\text{minimize } TC = \alpha \cdot TIC + \beta \cdot \text{TOMRC} + \gamma \cdot \text{TEMIC} \tag{1}
\]
The cost clause in formula (1) is expressed as:

\[ TIC = \sum_{t \in \Omega^t} \frac{(1 + i)^{-t}}{i} IC_{N}^{t} \]  \hspace{1cm} (1.1)

\[ \text{TOMRC} = \sum_{t \in \Omega^t} \frac{(1 + i)^{-t}}{i} (MC_{N}^{t} + MC_{D}^{t} + OC_{N}^{t} + OC_{D}^{t} + EC_{SS}^{t} + ENSC_{t}) \]  
\[ + \frac{(1 + \delta)^{-t}}{i} (MC_{P}^{t} + MC_{D}^{t} + OC_{P}^{t} + OC_{D}^{t} + EC_{SS}^{t} + ENSC_{t}) \]  
\[ \text{spreading operation, maintenance and reliability costs} \]  \hspace{1cm} (1.2)

In formula (1.2), the sum of the net present value of the operating, maintenance and reliability (OMR) costs for (I) the entire planning phase and (II) the OMR costs incurred after the last planning phase. Please note that (The costs in (i) depend on the OMR costs of the last planning stage. When allocating these costs after the last planning stage, it is assumed that there is a permanent investment planning period.

2.2. Constraints
(1) Load balancing constraints: The sum of total power generation, purchased power and unpowered power should be equal to the needs of each scenario, snapshot, and time period, as shown in (2).

\[ \sum_{k} \sum_{p} (g_{p,k,s,w,t}^{E} + g_{p,k,s,w,t}^{N}) + \sum_{s,s_{t}} g_{s,s,w,t}^{ss} + \delta_{s,w,t} = \delta_{s,w,t} \]  \hspace{1cm} (2)

(2) Investment limit: In practical problems, capital constraints always exist; therefore, the maximum allowable budget for DG investment in a certain year is limited by formula (3).

\[ \sum_{k \in \Omega^{k}} \sum_{p \in \Omega^{p}} IC_{p,k}^{N} (x_{p,k,t}^{N} - x_{p,k,t-1}^{N}) \leq \text{InvLim}_t \]  \hspace{1cm} (3)

3. Case Studies, Results and Discussions
3.1. Data and assumptions for case studies
The DGIP problem is coded with gams24.0™ and solved with cplex12.0™. The system considered in the study is a distribution network on Azores with a peak demand of 70 MW. The existing generators are shown in Table1.

In this system, various DG types with a capacity from 1 MW to 30 MW are considered as investment objects (see Table1). According to the general capacity-based DG classification, these belong to the small to medium DG category. In the case study the figures for the installation and maintenance costs of each of the distributed generating units considered are given in Table1. The hourly series of wind and solar PV generation for a year are obtained from different locations on the island.
Table 1 Data for existing and candidate generators

| No. | Generator type | Alternative | Installed capacity (MW) | $OC_{d,1}$ (€/MWh) | $MC_{d,1}$ (ME) | $EB_{d,1}$ tons of CO₂/MWh |
|-----|----------------|-------------|-------------------------|---------------------|----------------|---------------------------|
| 1   | Hydro          | Hydro       | 407                     | 7                   | NA             | 0.58                      |
| 2   | Geothermal     | GEOT        | 24                      | 5                   | NA             | 1.20                      |
| 3   | HFO1*         | HFO         | 88                      | 145.4               | NA             | 0.01                      |
| 4   | Wind           | WD 6        | 10                      | 17                  | NA             | 0.90                      |

b) Candidate generators

| No. | Generator type | Alternative | Installed capacity (MW) | $OC_{d,1}$ (€/MWh) | $MC_{d,1}$ (ME) | $EB_{d,1}$ tons of CO₂/MWh |
|-----|----------------|-------------|-------------------------|---------------------|----------------|---------------------------|
| 1   | Solar          | PV 1        | 1                       | 40                  | 3.00           | 0.06                      |
| 2   | Solar          | PV 2        | 3.5                     | 40                  | 3.83           | 0.08                      |
| 3   | Solar          | PV 3        | 40                      | 4.55                | 0.09           | 0.09                      |
| 4   | Solar          | PV 4        | 2.5                     | 40                  | 5.20           | 0.10                      |
| 5   | Solar          | PV 5        | 3                       | 40                  | 5.80           | 0.12                      |
| 6   | Solar          | PV 6        | 4                       | 40                  | 6.89           | 0.14                      |
| 7   | Solar          | PV 7        | 6                       | 40                  | 8.79           | 0.17                      |
| 8   | Solar          | PV 8        | 10                      | 40                  | 11.94          | 0.24                      |
| 9   | Wind           | WD 1        | 1                       | 17                  | 2.64           | 0.05                      |
| 10  | Wind           | WD 2        | 2                       | 17                  | 4.00           | 0.08                      |
| 11  | Wind           | WD 3        | 5                       | 17                  | 6.93           | 0.14                      |
| 12  | Wind           | WD 4        | 10                      | 17                  | 10.51          | 0.21                      |
| 13  | CCGT**         | CGT 1       | 30                      | 145.4               | 27.00          | 0.01                      |
| 14  | Biomass        | BM 1        | 20                      | 30                  | 80.00         | 3.00                      |

* Heavy fuel oil turbine, ** Combined cycle turbine ¹ Not applicable

3.2. Hypothetical Scenario Definition

Table 2 shows three evolutions in demand growth, expressed as low, medium, and high, each with equal realization probability. Similarly, the price of emissions is represented by three storylines (scenarios) with equal probability, as shown in the following table. In these separate scenarios, assuming two uncertain parameters are independent, we can have nine different combinations. These form a new set of scenarios used in the simulation. Based on this, a sensitivity analysis is performed. In addition, the effects of several other system parameters in addition to these parameters on the investment decision of distributed power are studied, and these parameters contain a certain degree of uncertainty.

Table 2 Demand growth and emission price scenarios

| Stages | Demand growth scenarios | Emission price scenarios (€/ton of CO₂) |
|--------|-------------------------|----------------------------------------|
|        | Low  | Medium | High | Low | Medium | High |
| T0     | 0%   | 0%     | 0%   | 5   | 5       | 5    |
| T1     | 2%   | 5%     | 10%  | 7   | 35      | 50   |
| T2     | 5%   | 10%    | 20%  | 10  | 50      | 115  |
| T3     | 7%   | 15%    | 30%  | 20  | 70      | 150  |

3.3. Sensitivity of DG Investment to Changes in Model System Parameters

Interest rate: The evolution of interest rate is still uncertain, so it may change at any time in the future. To see its impact on DG investment decisions, you can change other parameters by keeping their basic situation values. Generally speaking, DG investment will as interest rates fall, this is shown in Figure1, which clearly shows the decreasing trend of DG (especially renewable energy) investment.
Their share of total power generation follows a similar trend. This is consistent with financial theory, which states that higher interest rates will prevent investment because it will increase the expected return on investment, which will not incentive investment. For example, an interest rate of 0.02 causes all DG candidates of wind and solar types except pv1 and pv2 to invest (see Table1); while for an interest rate of 0.12, the investment made only includes pv7, pv8 and the DG of all wind energy types, the huge difference here highlights the sensitivity of investment decisions to interest rates.

DG penetration level coefficient: This factor is another relevant parameter that affects DG investment decisions. Intuitively, one may think that the higher this value, the higher the incentive to integrate more renewable energy, so the more DG investment high. However, this can only be maintained to a certain threshold, beyond which there seems to be little or no new investment. Figure2 clearly reflects this phenomenon. In the case study presented in this article, the threshold for the level of penetration it seems to be 40%. Below this level, DG's investment has steadily increased with the increase in penetration, from almost no investment at 10% to 7 investments at 40%. However, this is not the case with higher penetration even if the permeability level is set above 40%, no new investment is justified. As shown in Figure2, DG permeability has a significant impact on emissions and expected system costs. As expected, DG investment the increase is offset by higher reductions in operating and emissions costs, leading to a downward trend in expected system costs and total emissions as permeability increases. However, above 40%, the rate of change in both curves is negligible. Or, Figure3 shows DG investment as a function of DG penetration level factor. The results in this figure also reinforce the fact that DG investment shows a certain change as the level of this factor increases. When the DG permeability coefficient increases to a certain level (about 40%), the emission level will after the reduction, beyond this level, the change is not large. This indicates that the investment in DG has increased to this level. In addition, this is consistent with the previous statement.

Figure 1 The impact of discount rates on DG investment and wind and solar power

Figure 2 Emissions, investments, and expected system costs vary with DG penetration level factors.
Figure 3 Changes in DG investment with penetration levels and their impact on total CO2 emissions

4. Conclusions
In order to study the effects of variability and uncertainty of model parameters on DG investment decisions, this paper conducts a comprehensive experimental analysis of the sensitivity of DG investment to changes in several uncertain parameters. The purpose of this analysis is to determine the DG investment. The parameters that have the most impact. This can help planners design new methods and tools that best represent the most relevant sources of variability and uncertainty. Our analysis results generally show that uncertainty and variability are important for DG investment decisions both have important impacts. In fact, the degree of impact varies depending on the parameters. However, in general, ignoring or not fully considering the uncertainty and variability in model parameters can cause quantifiable costs. The analysis made in this article can it is useful for other researchers working in similar fields to identify the most relevant model parameters that require special attention in planning practice.

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