MODELING OF RISK AVERSION LINKED TO RENEWABLE ENERGY POLICY AND DECISION- MAKER BEHAVIOUR

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ABSTRACT

In recent years particular attention has been emphasized to different diversified means of energy production for the security of supply, availability, reliability, and robustness of electrical energy systems. The attention rests on the most effective preventive organization, at the cost of an economic investment which will be all the more profitable since the consequences of the breakdown are significant. Given the random nature of the failures of the existing electricity distribution networks and the intermittency of production, the decision to invest preventively in the electricity system is similar or not to an exposure to risk. Will the network manager then take the risk of not investing in a preventive policy, saving an investment, but under the threat of a failure requiring a more costly corrective intervention?An expected utility function models the tast and/or aversion to risk. We use the model of von Neumann and Morgenstern indicating that the rational choice amounts to maximizing the expected utility.The objective is to model risk aversion to the choice of a policy leading to the integration of renewable energies into the electricity system. Following a bibliographical approach, a methodology to model the behaviour of the risk averse decision maker using the exponential utility function has been presented. We provide a decision support tool to the decision maker that allows him to choose a corrective or preventive policy that best suits the electrical system and his preferences. We take into account the probabilities of the occurrence of failures within the framework of a defined policy, the associated costs and the degree of risk aversion of the decision-maker. Based on these elements, we provide a policy proposal that is the best compromise for the decision-maker. Scilab and Matlab software as used to plot utility curves and calculate failure probabilities. Several examples are treated and allow one to become familiar with the integration of risk aversion modeling in order to define a preventive policy for the power supply system.

INTRODUCTION

The power grid is an infrastructure that develops with time and involves decision-making that may be irreversible most of the time. Renewable energy integration capacity enhancement is the objective to allow the integration of variable renewable energy sources without curtailment. Distributed generation may be the best thing that has happened to the electric power industry in the recent decades, providing it with new capabilities that make electric power more valuable and capable of meeting a wider range of our civilization's energy needs than ever before[1]. The electrical distribution network and renewable distributed generation can be used together, rather than as independent and competing disciplines to together provide better service at lower cost figure 1.

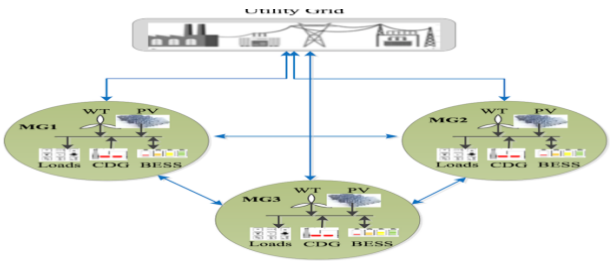

Figure 1: renewables integration structure

One heated topic is the uncertainty management associated with renewable variations and electricity load forecasting errors and failures in existing electrical distribution network. The utility function makes it possible to quantify the relevance of a policy of integration of renewable energies. Utility theory involves decision making under risk where the rational decision maker seeks to maximize the expectation of the utility function. A policy of corrective actions in the electrical distribution system generates costs. Preventive actions support corrective actions, for example security of supply, reliability. The decision to invest in renewables or not is similar to risk exposure. Not integrating (investing) renewable energies by limiting oneself to a corrective policy of the existing distribution system, exposes to a risk that is reduced by a preventive approach (renewable energy integration), but which incurs an investment cost. Risk defined as being the product of probabilities of occurrence and its consequences, therefore has no relationship with risk aversion is considered in this context. Risk aversion is therefore a behaviour that is revealed in situations where potential wealth is high but at risk, and therefore which reduces the likelihood of adverse consequences. Risk management has been received a lot of attention in the electric power industry to help market players hedge their sources of risk for different durations [2]. A multi-stage market equilibrium model of risk averse agents to analyze how the operation of hydroelectric reservoirs can be affected by the aversion profile is presented [3]. The behaviour of market participants is affected by their level of risk aversion, and the application of equilibrium-based models is a commonly used technique to simulate their behaviour.

The objective of the decision maker in risk management is either to maximize profit (e.g., the financial profile of electricity generation) or to minimize cost (e.g., the cost of supplying electricity to an industrial consumer).

A comparative analysis between risk aversion and strategic behaviour to identify situations in which both types of behaviour lead to the same result has been studied [4]. Engineering decisions are invariably made under subtle uncertainty. These uncertainties differ by their time scale, but are linked by the interactions between the state of the systems and the decisions to be made and result precisely from the different behaviours of the decision-maker. The expansion of electrical systems involves decisions to compare alternatives and the degree of uncertainty [4][5]. These are operating decisions that are based on investments in new energy production capacities and load shedding. Decision-making for the integration of renewable energies into electrical systems is plagued by uncertainties that affect the network manager. Energy supply from renewable sources is highly variable with relatively large capital investment. However, the integration costs are an insurer in terms of reliability (availability) against breakdowns. Indeed, risk aversion for the distribution system operator can be studied through three behaviours: risk taker, risk neutral and risk averse.

The tendency to overestimate a risk, which commonly comes from ignorance or fear, is a characteristic of a risk-averse attitude, while the tendency to underestimate a risk reflects a risk-accepting attitude. If a decision-maker neither overestimates nor underestimates a risk, his/her attitude is risk-neutral. Such attitudes depend on the context of the risk to the decisionmaker, including the relative likelihoods, types and magnitudes of losses, the social position of the decision maker and political factors. The theory of choice under uncertainty aims to provide a coherent framework of principles of rational behaviour to analyze and guide the attitudes of decision makers in the face of potential losses and/or benefits. Utility and decision theory is developed to characterize behaviour under risk. The decision is based on the assumption that the expected value in use is the appropriate decision criterion [6][7]. A common approach when making a decision is to base it on expected values. The expected value is an operation that multiplies the consequence of each event by its probability and sums over all possible events. Indeed, rather than seeking to minimize an average cost per unit of time, in utility theory, the risk-averse rational decision maker seeks to maximize a concave utility function. The presented study provides a framework for risk decision-making from a normative perspective where one questions the preference patterns that may lead to rational behaviour. Risk aversion policies require largescale integration of renewables into power systems modeled using the utility function methodology developed in economy. Risk aversion leads to a renewable energy integration policy that is more expensive on average, but which would entail less major expenditure. Will the network manager then take the risk of not investing in a (renewable) preventive policy, saving, investment but under the threat of a failure requiring a more costly corrective intervention? We model risk aversion in relation to the choice of a policy leading to the integration of renewable energies into electrical systems. Indeed, integrating renewable energies into electrical systems, whether or not preventive is a risk that can cost the public electricity service. The modeling of this bet is the subject of this paper. Taste (predilection and/or aversion to risk) is a model linked to the notion of utility. The rest of the document is organized as follows. Section 2 exposes the problem. Sections 3&4 present the preliminary modeling and the resolution methodology. Sections 4&5 illustrate an application of renewable integration and the conclusion.

RISK-INFORMED DECISION MAKING FOR RENEWABLES INTEGRATION: PROBLEM STATEMENT

The risk averse decision maker prefers a certain prospect (or lottery) to all other risky prospects. The decision maker chooses one bet over another if and only if there is a utility function u such that the expected utility of one is greater than that of the other. Utility theory, proposed by von Neumann and Morgenstern [2], introduced the notion of a utility function to relate a quantitatie measure of consequence, such as euro loss. The risk attitude of a decision-maker reflects his/her tendency to overestimate or underestimate a risk with which he/she is confronted. First of all, the word ‘risk’ denotes variability in cash flows. For example, a risk averse person would rather receive 50 € for certain than receive either 200€ or nothing depending on the toss of a coin. Let a lottery be a discrete probability distribution p_i of a set of consequences $x_i \in \mathbb{R}$ knowing that the probabilities are known in advance. Suppose N consequences (resp. monetary sum) and whose values represented $x_1, x_2 \dots x_n$ attached to the probabilities p_i represented $p_1, p_2, \dots\ p_n$ such that $0 \leq p_i\ \leq p_1$ for $x_i \in 1,2,\dots,N$ and $\sum_i^n p_i = 1$. To illustrate the role of risk attitude, in figure 1 below, we consider two lotteries, $\boldsymbol{L}_1$ et $\boldsymbol{L}_2$. $\boldsymbol{L}_1$ offers a consequence of 150€ with a probability $p = 1$ and $\boldsymbol{L}_2$ is given with a probability $p = 0.5$ of winning a consequence of 300€ and a probability $1 - p = 0.5$ of losing with a consequence of 0€. The behaviour of the decision maker is modelled using a utility function of the form $u(x) = x^2$. So that $\boldsymbol{L}_1 = p * x^2 = 22500$ and $\boldsymbol{L}_2 = (p) * x^2 + (1 - p) * x^2 = 45000$. According to the characteristics of the lotteries and the behaviour of the decision maker through the utility function, $\boldsymbol{L}_2$ is preferred to $\boldsymbol{L}_1$ lottery and therefore the choice is risk, $u(\boldsymbol{L}_2) > u(\boldsymbol{L}_1)$. The decision maker prefers $\boldsymbol{L}_2$ rather than $\boldsymbol{L}_1$. Decision making is illustrated in Figure 1 below.

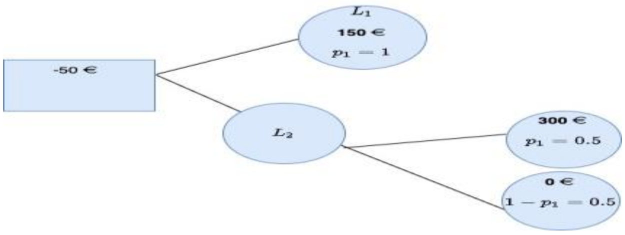

Figure 2: risk taking decision

Risk aversion can be modeled via a concave utility function. Figure 2 below illustrates the utility curve corresponding to the behaviour of the risk averse decision maker. The y- axis defines the utilities between 0 and 1 and the x-axis shows the wealth of the lottery. Indeed, such a configuration indicates that the worst case in terms of wealth corresponds to the utility 0, $u(0)$ = 0 and the case favorable to the utility 1, $u(1)$ = 1.

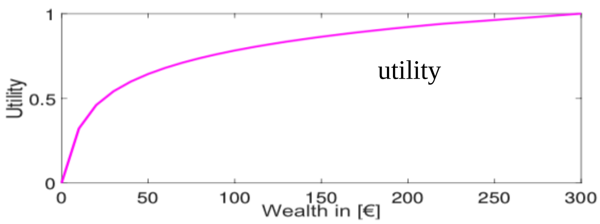

Figure 3: Utility curve

unfortunately, this form of exponential function only allows one behaviour to be determined. It does not make it possible to determine the negative values of the costs when it comes to risk aversion behaviour.

PRIOR MODELING :LOTTERY

In figure 4 below, the difference compared to the coin toss lottery (figure 3 above) is that here we consider the costs of policies for integrating renewables into electricitrical systems. The risk situation of the manager is to ensure the availability of supply by preventively integrating into the electricity distribution system, renewables and/or by strictly executing a corrective policy of the distribution system. How can we model this behaviour and know if the network operator is more risk averse or risk predilection. As shown in figure 4 below, we translate the network manager's condition into lottery terms. The expected utility $\mathbb{E}(u(x))$ expresses the property of the decision maker's behaviour that maximizes his utility function when faced with a choice of a risky alternative and a certain alternative of monetary gains. Suppose that $\forall A_1, A_2 \in \boldsymbol{L}(x)$such as x is the set of consequences of a decision problem $\boldsymbol{L}(x)$ finished lotteries with strategies.

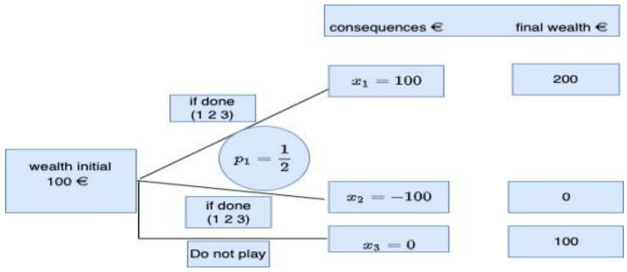

Figure 4: model of a lottery

Let $A = [p_x(1-p)y]$, a strategy that wins x with p and y with $1-p$. After comparing two strategies, the decision maker can have the choice according to his preferences $A_1 > A_2$, the strategy $A_1$is preferred in the strategy A_2. We deduce that for $A_1 = [p_x x_1; (1-p_1)y_1]$ and $A_1 = [p_x x_2; (1-p_2)y_2]$ there is a utility function u on the set of consequences such; $p_1 u(x_1) + (1-p_1)u(y_1) > p_2 u(x_2) + (1-p_2)u(y_2)$
or

$$\sum_i p_1 u(x_1) + (1-p_1)u(y_1) > \sum_i p_2 u(x_2) + (1-p_1)u(y_2) \quad [1]$$

the expected utility associated with the gains A_1 greater than the expected utility associated with gains A_2. The expected utility of the winnings of the different lotteries is compared to the expected utility of the winnings that these lotteries allow, by representing the different behaviours of the decision maker by the utility curves.

SOLUTION METHODOLOGY

First, the objective is to choose between the two policies, corrective and preventive. To solve the problem we propose the form of the utility function as follows;

$$u(x) = 1 - (1 - e^{(-\lambda x)} \quad [2]$$

such as $u'(x) = (1 - e^{(-\lambda x)})$ and $u''(x) = \lambda^2 e^{(-\lambda x)}$. The expected utility associated with [2] is as follows;

$$\mathbb{E}(u(x)) = p_1 u\left(1 - e^{(-\lambda x)}\right) + p_2 u\left(1 - e^{(-\lambda x)}\right) \quad [3]$$

where if write $u(x_i)$ in [2-3] we would read the utility of a sum of money represented by a consequence x_i and p_i being the probability of occurrence of the consequence x_i. Unfortunately [2] can only determine one behaviour. It also does not allow us to determine the negative values of the costs when it comes to risk aversion behaviour. In the case of application in this context, we use the form of the specific utility function concave for the gains and convex for the losses which determines the behaviours of the decision maker as follows;

$$u(\mathbb{E}(x)) = \frac{1}{1-e^{-\lambda}}\left(1 - e^{-\lambda(\frac{C_{max}-X_i}{C_{max}})}\right) \quad [4]$$

where C_{max} is the maximum value of potential cost et x_i consequences. The parameter λ is called the risk aversion parameter because it characterizes the convexity of the utility function and thus quantifies risk attitude. The form of the exponential utility function [4] is exploited for both policies. The expected associated utility of corrective policy is as follows,

$$\mathbb{E}(x_1) = \left(\frac{1}{(1-e^{(-\lambda)})} * \left(1 - e^{\left(-\lambda*\left(\frac{(C_{max}-x_1)}{C_{max}}\right)\right)}\right)\right) \quad [5]$$

and the expected associated utility of corrective policy is as follows;

$$\mathbb{E}(x_2) = \left(\frac{1}{(1-e^{(-\lambda)})} * \left(1 - e^{\left(-\lambda*\left(\frac{(C_{max}-x_2)}{C_{max}}\right)\right)}\right)\right) \quad [6]$$

and the utility expectations of two policies are determined by maximizing the utility function as follows,

$$\mathbb{E}(u(x)) = p_1\left(\frac{1}{1-(e^{(-\lambda)})}\right) * \left(1 - e^{\left(-\lambda*\left(\frac{(C_{max}-x_1)}{C_{max}}\right)\right)}\right) + p_2\left(\frac{1}{1-(e^{(-\lambda)})}\right) * \left(1 - e^{\left(-\lambda*\left(\frac{(C_{max}-x_2)}{C_{max}}\right)\right)}\right) + p_3\left(\frac{1}{1-(e^{(-\lambda)})}\right) * \left(1 - e^{\left(-\lambda*\left(\frac{(C_{max}-x_3)}{C_{max}}\right)\right)}\right) + p_4\left(\frac{1}{1-(e^{(-\lambda)})}\right) * \left(1 - e^{\left(-\lambda*\left(\frac{(C_{max}-x_4)}{C_{max}}\right)\right)}\right) \quad [7]$$

to say that $\mathbb{E}[u(x)]$ express the property of the behaviour of the decision maker which aims to maximize his utility function faced with a choice of a risky alternative and the certain alternative in the perspective of monetary gains.

APPLICATION TO THE POLICY OF INTEGRATION OF RENEWABLE ENERGY IN ELECTRICITY DISTRIBUTION SYSTEMS

We apply the issue encountered in economics to the case of renewable energy integration shown in figure 5 below. Risk taking is a lottery, that is to say a discrete distribution of probability p_i over a set of consequences x_1. p and $1-p$ refer to the probabilities that the electrical distribution system will work and will not work (a corrective policy). p' and $1-p'$ are the operating and failure probabilities for the preventive policy. $R(t) = p$ represents the probability that the distribution network has operated without failure at time t. $1 - R(t) = 1 - p$ is the probability that the distribution network operated with zero, one or two breakdowns at time t.

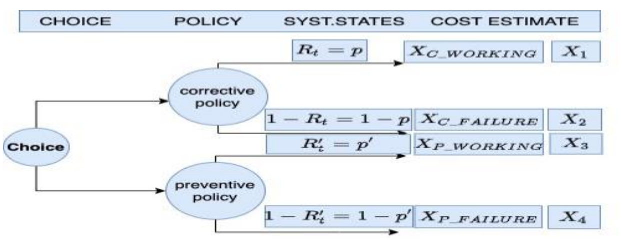

Figure 5: representation of the lottery

In figure 5 above, the decision maker must make the choice: or he uses the corrective policy. In the event of a breakdown, it can be put back into service. Either it invests preventively in renewable energies such that in the event of a breakdown, the security of supply is ensured, the duration of the breakdown and the stress on customers are reduced and the performance of the system is guaranteed. In the probability calculations of the breakdowns, we used the Weibull law as follows;

$$T = 1 - e^{-(t/\eta)^{\beta}} \quad [6]$$

with the parameters: $\eta = 5$ and $\beta = 3$. T is the probability of having at least zero, one, and two breakdowns. We use the scilab code to estimate by simulations, the breakdowns time that applies over a certain observation time. We consider that for each breakdowns, a loss and policy costs are imputed. In the table 1 below illustrates the numerical values of breakdowns and imputed loss and policy costs.

Table 1: numerical values

Corrective cost	5000	€
Loss cost	500	€
Labor cost	300	h
Repair time	8	€
Total cost of breakdown	11400	€
Preventive total cost	3000	€

The simulation results are shown in table 2(corrective policy) and table 3 (preventive policy) below. The three columns from left to right indicate failure numbers, probabilities and costs.

Table 2: corrective policy

breakdown	corrective policy		
	proba	cost	proba*cost
0	0.37	0	0
1	0.58	11400	6726
2	0.04	22800	912

Table 3: preventive policy

breakdown	preventive policy		
	proba	cost	proba*cost
0	0.98	3000	2700
1	0.015	14400	1296
2	0.0003	25800	154.8

Figure 5 above is reformulated in figure 6 below;

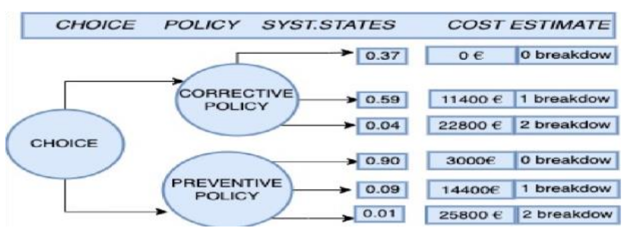

Figure 6: renewable integration policy

Figure 7 below illustrates the two behaviours of the decision maker. If the decision maker has risk aversion, he chooses the preventive policy with λ=3 (concave curve). If the decision maker has a predilection (taste for risk), he chooses the corrective policy for λ = −3(convex curve). The abscissa axis represents the utilities while the ordinate represents the costs. When $\lambda = 0$ the decision maker is indifferent (neutral).

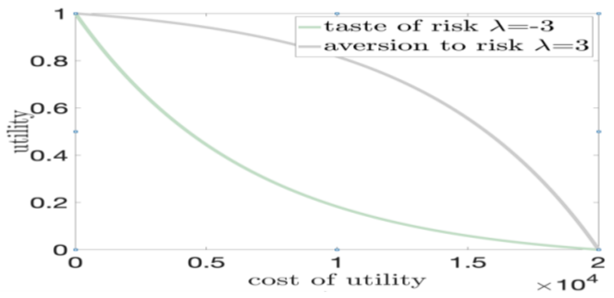

Figure 7: decision maker behaviours

The sensitivity analysis with $\lambda = 2$ and $\lambda = -2$ then $\lambda = 1$ et $\lambda - 1$is indicated in figure 8 below.

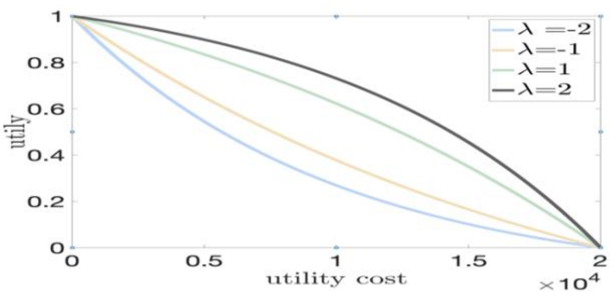

Figure 8: decision maker behaviours(sensitivity)

According to Figure 6 above, the decision maker makes the decision by comparing the two expectations of the policy and according to the one that maximizes its utility. The decision maker makes the decision by comparing the two policies based on which one maximizes its utility in table 4 below. The expectation $\mathbb{E}(u(x))$ is lower than the expected utility $u(\mathbb{E}(x))$ using the preventive policy where the decision maker opts by taking the risk of investing in renewables. The choice of the decision maker is an optimal policy which reduces the probability of failure, and which maximizes the expectation of the utility function $E(u(x))$ by taking into account the behaviour of the decision maker in the face of risk.

Table 4: corrective policy($\lambda = 3$) and preventive policy ($\lambda = 3$)

aversion parameter	$\lambda = 3$	
policy	corrective	preventive
$u(\mathbb{E}(x))$	0.9250	0.9674
$\mathbb{E}(u(x)$	0.8869	0.9498
aversion parameter	$\lambda = -3$	
policy	corrective	preventive
$u(\mathbb{E}(x))$	0.4185	0.4629
$\mathbb{E}(u(x)$	0.5278	0.4835

CONCLUSION

The objective is to use a modeling of decision-maker behaviour in the context of policy choices: to invest preventively in renewables or not. Not investing in renewables by limiting yourself to a corrective policy (of the distribution network) exposes you to a risk that is reduced by a preventive approach, but which induces an investment cost. Following a bibliographic analysis, this paper has presented the interest of a utility function of von Neumann transposing to the case of integration of renewable energies in the electrical distribution system. The choice of a renewable energy integration policy is a research subject of major interest for the distribution system operator. Decision-making is complex because, in addition to the difficulty of making a choice among other policies, the decision-maker must deal with uncertainty. The model can be applied to any policy if the consequences and their probabilities of occurrence can be quantified.

REFERENCES

[1] Willis, H Lee and Walter G Scott (2018). Distributed power generation: planning and evaluation. Crc Press.

[2] Eun Jeong Cha; Bruce R. Ellingwood et al, The role of risk aversion in nuclear plant safety decisions, Georgia Institute of Technology, Atlanta, 2013.

[3] Denton, M.; Palmer, A.; Masiello, R.; Skantze, P. Managing market risk in energy. IEEE Trans. Power Syst. 2003, 18, 494–502.

[4] Steffen, Comparative analysis of risk-aversion and strategic investment behaviour in generation expansion, ScienceDirect 210(2022)

[5] Khazaii, Javad (2014). Energy-efficiency HVAC Design: An Essential Guide for Sustainable Building

[6] Grechuk, Bogdan and Michael Zabarankin(2014). "Risk averse decision making under catastrophic risk". In: European Journal of Operational Research239.1, pp. 166–176.

[7] De Queiroz, A.R. Stochastic hydro-thermal scheduling optimization: An overview. Renew. Sustain. Energy Rev. 2016, 62, 382–395.