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Decision making and risk aversion under uncertainty in energy renewable and operational of flexibility of distribution system network

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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 as 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 to exposure to risk. Will the network manager then take the risk of not investing in a preventive policy, saving investment, but under the threat of a failure requiring a more costly corrective intervention? An expected utility function models the taste and/or aversion to risk. We use the model of von Neumann and Morgenstern, indicating that rational choice amounts to maximizing the expected utility. In this paper, a new standard methodology of uncertainty modeling techniques for decision making process is proposed. The paper provides 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. A decision support tool is provided and allows choosing a corrective or preventive policy that best suits the electrical system and the preferences of the decision maker. The objective is to model risk aversion to the choice of a policy leading to the integration of renewable energies into the electricity system. 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. Several examples are treated and allow one to become familiar with the integration of risk aversion modeling to define a preventive policy for the power supply system.

Keywords: renewable energy resources, advanced energy technologies, energy systems, reliability

1. INTRODUCTION

The energy sector is called upon to question itself deeply. The energy transition, consisting of increased use of green energy sources (wind, sun, etc.), is increasingly becoming a reasonable, even essential, alternative. Renewable energy integration capacity enhancement is the objective that allows the integration of variable renewable energy sources without curtailment. The advent of distributed generation may be the best thing to happen to the electric power sector in decades, giving it new capabilities that increase its value and enable it to better address a variety of energy needs in our society [1]. The electrical distribution network presents strong opportunities for redesign with significant improvements, including incorporating renewable energy sources. Distributed generation and electric power systems can deliver better service at cheaper costs than either can alone when used together rather than as distinct, competing disciplines and perhaps in very unconventional ways as shown in Fig.1 below. Uncertainty management related to intermittent production from renewable sources and inaccurate load forecasts in the current electrical distribution network are two contentious issues. Exposure to risk is equivalent to the choice of investing in renewable energy or not.

Fig. 1 Renewable energy integration

In exposes one to a risk that is mitigated by a preventive approach (renewable energy integration), but which comes at a cost in terms of investment. Risk management has received a

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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 has been 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 this 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 the situations in which both the types of behaviour can lead to the same result has been studied [4]. Risk aversion is not related to risk, which is defined as the sum of occurrence probabilities and their effects in this context. Risk aversion at the heart of economic and financial thinking is the behavior that reflects the desire to avoid any risky decision, and therefore reduces the likelihood of adverse consequences. Engineering decisions are invariably made with subtle uncertainties.

These uncertainties differ in their time scale, but they are connected by the interactions between the state of the systems and the decisions to be made and come directly from the many ways in which the decision-maker behaves. The expansion of electrical systems involves decisions to compare the alternatives and the degree of uncertainty [4][5]. These are operating decisions that are based on the investments in new energy production capacities and load shedding. Uncertainties that affect the network manager hinder decision-making for the integration of renewable energies into electrical systems. Renewable energy sources have a comparatively high capital investment and a very variable energy supply. However, the integration costs act as an insurer for availability (resp. reliability) against failures.

In fact, three behaviours risk taker, risk neutral, and risk averse can be used to study risk aversion for distribution system operators. A risk-averse attitude is characterized by the propensity to overestimate risks, which is frequently the result of ignorance or fear, whereas a risk-accepting attitude is reflected by the propensity to underestimate risks. A decision-mindset maker's is risk-neutral if they don't exaggerate or underestimate a risk. Such attitudes depend on the context of the risk to the decision-maker, 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 behavior 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 behavior under risk. The decision is based on the assumption that expected value in use is the appropriate decision criterion [6][7].

Making decisions based on expected values is a typical strategy[8]. The anticipated value is a calculation that adds up all potential events and multiplies each event's consequence by its probability. In fact, according to utility theory, the risk-averse rational decision maker aims to maximize a concave utility function rather than minimizing an average cost per unit of time. The study that is being presented offers a normative framework for risk decision-making where one examines the preference patterns that might result in reasonable action. Large-scale integration of renewables into power systems modelled using the utility function methodology developed in economics is necessary for risk-aversion policies.

Risk aversion leads to a renewable energy integration policy that is more expensive on average but would entail less major expenditure. Will the network manager (resp. decision-maker) would 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? In this study, we modelled risk aversion in connection to the selection of a policy promoting the incorporation of renewable energies into electrical systems. In fact, whether or not it is preventative, integrating renewable energies into electrical systems is tantamount to taking a risk that could cost the public electricity service. The focus of this work is the modelling of this wager. Taste is a model that is connected to the idea of utility (or, alternatively, preference and/or aversion to risk). The remaining portions of the text are arranged as follows. Section 2 reveals the issue. The initial modelling and resolution methodology are presented in Sections 3 and 4. The implementation of renewable integration is shown in Sections 4 and 5, along with the conclusion.

2. METHODOLOGICAL APPROACH

2.1 Grid outage modeling and simulation

The main grid is modeled to be able to concurrently be providing and receiving power from PV and wind generators. The radial network topology is widely used in LV distribution networks, where faults occur frequently and the fatality level of the fault (the number of consumers affected by the fault) is high. A power grid topology can be mathematically represented by a graph $\mathcal{G}(\mathcal{N},\mathcal{E})$ where i denotes a node within the node set $\mathcal{N}$ and $l=(i,j)$ the link between node i and j in the line l edges set $\mathcal{E}$. Consider topological parameters related to network topologies such as failure shown in fig 2 below. The odds that the electrical distribution system will function properly or not are denoted by the words probability p and $1-p$ (a corrective policy). The failure and functioning probabilities for the preventative measure are p' and $1-p'$, respectively. $R(t)=p$ 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 (0), one (1) or two (2) outages at time t. A strategy (resp. policy) is a rule for choosing an action at each point where a decision might need to be made. In figure 2, in case breakdown, the system is put back into service (as good as new).

2.2 Probability of outage

This promotes system performance and breakdown prevention. In the probability calculations, we used the Weibull law probability of having at least zero (0), one (1), and two (2) one failure. Weibull distribution is able to closely fit with the five-year outage data. Weibull distribution has been used to model the distribution grid outage. Outage durations or repair times of a component can be represented by this distribution [9][10], and its cumulative distribution function (cdf) for a random variable t can be given as,

$$CDF = T(t|\eta\beta), = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad [1]$$

with $\eta = 5$ (scale parameter) which represents the order of magnitude and co-incides with the failure time and $\beta = 3$ (shape parameter) which represents the dispersion of failure times, their distribution (dispersion) over time. T represents the random variable describing the time to failure, and therefore the probability of having outages in the interval (0,t]. By fitting a Weibull cdf to the set of historical data, the values of a and b are determined; these characteristic parameters permit us to get a calibrated Weibull distribution with the actual distribution grid outage data. We use the scilab code to estimate by simulations, the failure time that applies over a certain observation time. The costs of imputed loss and the numerical values of failures are shown in table 1.

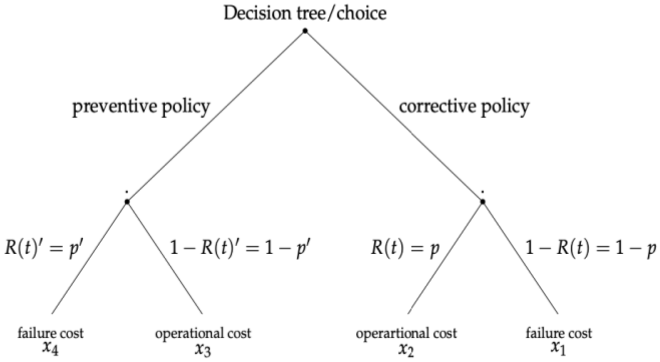


Fig 2: composition of event-wise recourse adaptions

corrective cost	5000	€
loss cost	500	€
labor cost	300	€
repair time	8h	h
total cost of failure	11400	€
preventive total cost	3000	€

Table. 1 Numerical values

The three failure scenarios corresponding to the policies and the results of the simulations3700(0 failure),5900(1 failure), 400(2 failures) table 2 below.

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

Table. 2 Corrective policy

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

Table.3 Preventive policy

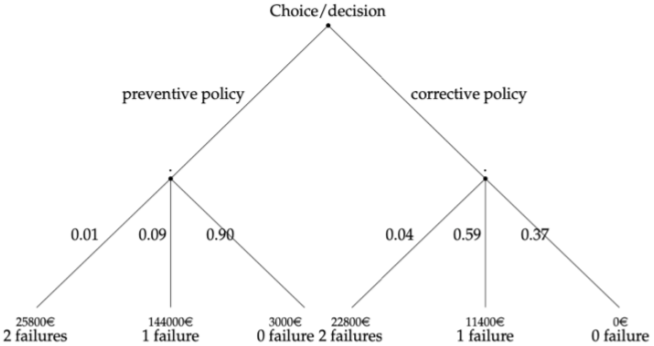


Figure 3: policy of integration renewable energy

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

Table.4 Corrective policy and Preventive policy

For an observation, the sequence of power cuts shown in figure 4 below.

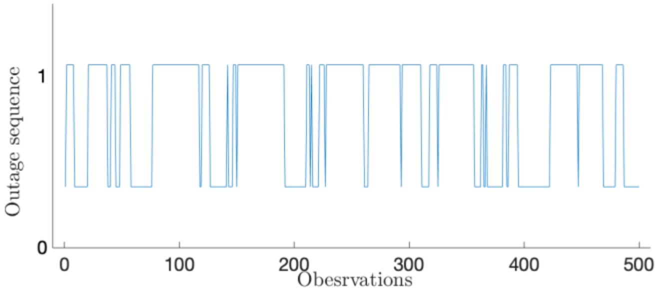


Figure 4: outage sequence

2.3 Load

The uncertainty of load demand can be modeled using the normal or Gaussian probability density function $\mathcal{N}(\mu, \sigma)$ based on average values u_{LOAD} and the standard deviation σ_{LOAD} witch vary according to the time of day $t \in \mathcal{D} = 0, \ldots 23$ with specific minimum and maximum values as follows;

$$f(P_{load}|u_{load}, \sigma_{load}) = \frac{1}{\sigma_{P_{load}}\sqrt{2\pi}}\left[\frac{\left(P_{load}-\mu_{P_{load}}\right)^2}{2\sigma_{load}^2}\right] \qquad [2]$$

where P_{load} the peak active power of the load request, $\mu_{P_{load}}$ and σ_{load} mean and standard deviation respectively.

2.4 PV

The PV power output directly depends on the global solar irradiation incident on PV panel surface and the ambient temperature of the location. For the site considered in the PV panel surface and the ambient temperature of the location,

$$PV = (1-\delta)A_{PV}\, I_{PV}\eta_{PV} \qquad [3]$$

where I_{PV} irradiation of PV includes the area A_{PV} (m^2) of the PV solar the δ is the performance degradation factor (0.002 and 0.007 per year).

2.5 Wind

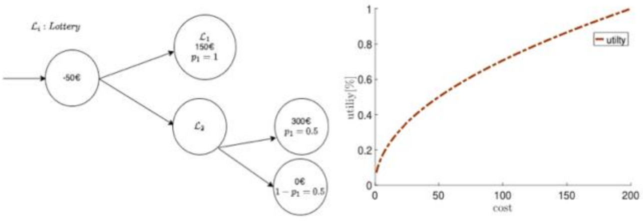
The conversion of kinetic energy present intermittently in the wind as mechanical energy, usually in the form of rotation of a shaft as follows;

$$P = \frac{1}{2}\,\rho A v^2 C_P \qquad [4]$$

where P is the power delivery in W, ρ is the area density in kg. m^3; A is the area swept by the rotor (π^2) for a wind turbine of radius R of circle.

3. METHODOLOGICAL APPROACH

Utility theory, proposed by von Neumann and Morgenstern [2], introduced the notion of a utility function to relate a quantitative measure of consequence, such as euro loss. A decision-risk maker's attitude indicates his or her propensity to exaggerate or underestimate a risk that must be considered. First of all, "risk" refers to the variability of 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. The utility of a sum of money y is $U(x)$, where $U' > 0$ et $U'' < 0$, the prime numbers which designate the differentiation. Let a lottery be a discrete probability distribution pi of a set of consequences $xi \in \mathbb{R}$ knowing that the probabilities are known in advance. Suppose N consequences (resp. monetary sums) and whose values represented $x_1, x_2 \ldots xn$ attached to the probabilities pi represented $p_1, p_2, \cdots p_n$ such that $0 \leq pi \leq p_1$ for $xi \in 1,2, \ldots, N$ and $\sum_i^n p_i = 1$. To illustrate the role of risk attitude, we assume that initial wealth of that the decision maker has 50€. Consider two lotteries, $\boldsymbol{L}1$ et $\boldsymbol{L}2$, $\boldsymbol{L}1$ offers a consequence of 150€ with a probability $p1$ and $\boldsymbol{L}2$ is given with a probability p equal to 0.5 of winning a consequence of 300€ and a probability $1-p$ equal to 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 $\boldsymbol{L}_1 = p_1 * x^2 = 22500$ and $\boldsymbol{L}_2 = p_1 * x^2 + p_1 * x^2 = 45000$ .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. Risk aversion can be modeled via a concave utility function. Figure 2 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. In fact, such a configuration shows that the utility $u(0) = 0$ corresponds to the worst situation in terms of wealth, and favorable case to utility1, $u(1) = 1$. Unfortunately, this form of exponential function fig.1(b) can only determine one behavior. Risk-averse is disinclined or reluctant to take risks.



(a) risk taking decision (b) Utility of money

Fig.5 Risk taking decision and utility curve linked to the risk aversion behavior

3.1 *Prior modeling: lottery*

The risk position for the manager is to ensure supply availability by proactively integrating renewable energy sources, the electrical distribution system, and/or by rigidly enforcing a corrective policy of the distribution system. The question is how can we simulate this behaviour and determine if the network operator prefers taking on risk or is more risk averse. As shown in Figure 4 below, we translate the network manager's condition into lottery terms. In fact, the difference between this lottery and the coin toss lottery is that in this case we take into account the expenses of the policies for integrating renewables into electrical networks. We consider that the utility is maximum if the cost is minimum and therefore in the application, we will need a specific utility function. To start, we assume a preference relation $u_i(a) \geq b_i(b)$ where a is preferred to b of the set of players (decision maker), indexed by $i \in 1,2, \ldots, N$. We refer to the values of such a function as payoffs(utilities). 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 $A_{(.)}$.

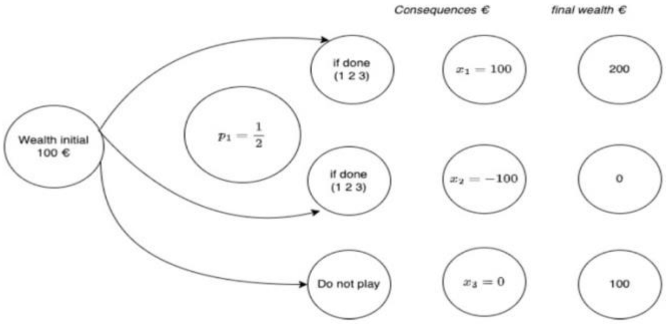


Figure: *6 Model of lottery*

Expected utility (expected and/or payoff) $u(\mathbb{E}(x))$ make it possible to match the utility associated with the final wealth (whether we add a payoff or subtract a loss). 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. Let $A = [px(1 - p)y]$, 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 $A1 > A2$, the strategy $A1$is preferred in the strategy $A2$. We deduce that for $A1 = [pxx1;\ (1 - p1)y1]$ and $A1 = [pxx2;\ (1 - p2)y2]$ there is a utility function u on the set of consequences such $p1u(x1) + (1 - p1)u(y1) > p2u(x2) + (1 - p2)\ u(y2)$ or $\sum i\ p1\ u(x1) + (1 - p1)u(y1) > \sum i\ p2\ u(x2) + (1 - p1)u(y2)$. The expected utility associated with the gains $A1$ greater than the expected utility associated with gains $A2$. 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 (resp. attitudes) of the decision maker by the utility curves.

4. SOLUTION METHODOLOGY

First, we determine the expected utility as follows,

$$u(\mathbb{E}(\mathrm{x})) = u(x_1p_1 + x_1p_1) \qquad [5]$$

where $u(xi)$ in [2] that one would read the utility of a sum of currencies represented by a consequence xi and pi being the probability of occurrence of the consequence xi. Then the determination of the expected utility noted $\mathbb{E}[u(x)]$ which makes it possible to 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. The principle of expected utility is based using relation (3), below as follows;

$$\mathbb{E}(u(x)) = p_1u(x_1) + p_2u(x_2) \qquad [6]$$

where $u(x) = (1 - e^{(-\lambda x)})$ with $u'(x) = (1 - e^{(-\lambda x)})$ and $u''(x) = \lambda^2 e^{(-\lambda x)}$. We rewrite [3] as follows;

$$\mathbb{E}(u(x)) = p_1u(1 - e^{(-\lambda x)}) + p_2u(1 - e^{(-\lambda x)}) \qquad [7]$$

and for the application, we use the form of the utility (specific utility function) function concave for the gains and convex for the losses [2] which determines the behaviors of the decision maker as follows;

$$u(\mathbb{E}(x)) = \frac{1}{1-exp^{-(\lambda)}}\left(1 - exp^{\lambda\left(\frac{cmax - x_1}{cmax}\right)}\right) \qquad [8]$$

where $Cmax$ is the maximum value of potential cost et xi consequences. The parameter λ (Aaron &Pratt) is called the risk aversion parameter because it characterizes the convexity of the utility function and thus quantifies risk attitude.

$$\begin{cases} \mathbb{E}(x_1) = \frac{1}{1-exp^{-(\lambda)}}\left(1 - exp^{\lambda\left(\frac{cmax - x_1}{cmax}\right)}\right) \\ \mathbb{E}(x_2) = \frac{1}{1-exp^{-(\lambda)}}\left(1 - exp^{\lambda\left(\frac{cmax - x_2}{cmax}\right)}\right) \end{cases} \qquad [9]$$

and the utility expectations of two policies are determined by maximizing the utility function as follows[7],

$$\begin{aligned} \mathbb{E}(u(x)) &= p_1\left(\frac{1}{1-exp^{-(\lambda)}}\right).\left(1 - exp^{\lambda\left(\frac{cmax - x_1}{cmax}\right)}\right) \\ &= +p_2\left(\frac{1}{1-exp^{-(\lambda)}}\right).\left(1 - exp^{\lambda\left(\frac{cmax - x_1}{cmax}\right)}\right) \\ &= +p_3\left(\frac{1}{1-exp^{-(\lambda)}}\right).\left(1 - exp^{\lambda\left(\frac{cmax - x_1}{cmax}\right)}\right) \qquad [10] \\ &= +p_4\left(\frac{1}{1-exp^{-(\lambda)}}\right).\left(1 - exp^{\lambda\left(\frac{cmax - x_1}{cmax}\right)}\right) \\ &= +p_1 \ldots \end{aligned}$$

5. CASE OF STUDY: APPLICATION TO THE POLICY OF INTEGRATION OF RENEWABLE ENERGY IN ELECTRICITY DISTRIBUTION SYSTEMS

We apply the issue encountered in economics to the example of renewable energy integration in the electrical system shown in figure 6. A discrete distribution of probability p_i across a collection of consequences x_i is what makes taking a risk a lottery. We take into account both corrective and preventive measures with winning and losing outcomes connected to probability. The decision-maker in figure 7 must decide whether to use the remedial policy or not. The system is put back into operation after a malfunction. Either invest ahead of time (in renewable energy), or have a backup plan in place in case the system malfunctions.

5.1 Results and Discussion

The integration policy of renewable figure 2 above is reformulated in figure 3 below. The three categories of conduct that need to be identified are risk aversion, risk predisposition, and indifference. Utility curves, which might be concave, convex, or linear, translate the decision-makers actions. The two decision-maker behaviours are depicted in Figure 6. Given his reluctance to taking risks, the decision-maker opts for the preventative measure when λ = 3. (concave curve). The decision-maker favours or enjoys risk; as a result, he selects the corrective measure for λ = -3 (convex curve). Positive values are disliked by the decision-maker. The expenditures are represented by the ordinate, whereas the utilities are represented by the abscissa axis. When $\lambda > 0$, the preventive course of action is picked. When $\lambda < 0$ is present, the decision-maker selects the corrective policy out of preference or taste. The decision-maker is uninterested when $\lambda = 0$ (neutral) fig.6 below.

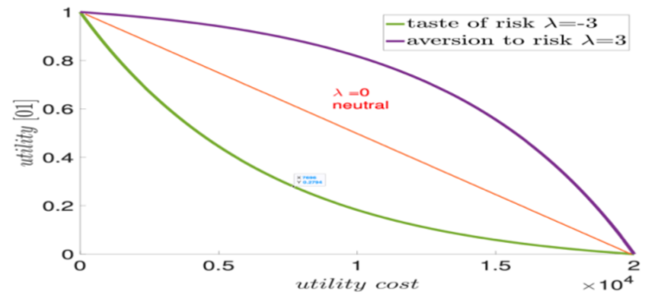


Fig.7 *Decision maker behaviors*

The sensitivity analysis is performed using the aversion parameter set to $\lambda = 2$ and $\lambda = -2$ then $\lambda = 1$ et $\lambda - 1$ figure.8 below.

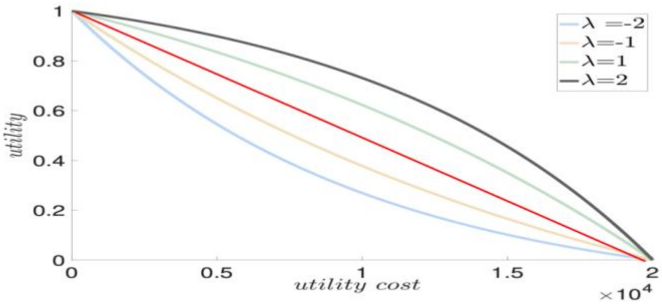


Fig.8 Decision maker behaviors(sensitivity)

Figure 7 suggests that the decision-maker compares the two policy expectations and chooses the one that maximizes the policy's utility. While the mathematical expectation can be used to justify some decisions, it cannot explain behaviour. The decision-maker weighs the two policies to see which one optimizes its utility (see table 2&3), then chooses between them.

When implementing a preventive approach and choosing to take the risk of investing in renewable energy, the expectation $\mathbb{E}(u(x))$ is lower than the utility $u(\mathbb{E}(x))$ expectation. By taking into account the decision-makers behaviour when faced with risk, the decision-maker's selection is an optimal strategy that minimizes the likelihood of failure and maximizes the expectation of the utility function $E(u(x))$. In figure 9 below, the energy produced by wind power and solar panels is reinjected into the feeder, particularly during network outages and/or load shedding. Increased investment in renewable energy can increase the reliability of the existing network and therefore reduce the duration of power interruptions to the electricity network.

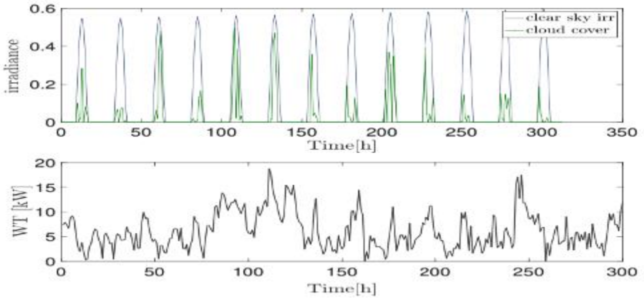


Figure 9: policy of integration renewable energy

2. CONCLUSIONS

Following a review of the literature, we presented the estimate approach in the context of a utility function, applying it to the situation of an electrical distribution system with a renewable energy application. The goal is to utilize a model of decision-maker behaviour in the context of political decisions on whether to invest in renewable energy in advance or not. By uncertainty in addition to finding the best option among competing policies. If the repercussions and their probabilities of occurring can be quantified, the model can be applied to any policy. Choice of a renewable integration policy is a research subject of major interest for the distribution network operator. Utility function of von Neumann transposing to the case of integration of renewable energies in the electrical distribution system.

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