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# Behavioral perspective of power systems' decision makers

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ABSTRACT

Several power system problems require solutions in an uncertain environment. According to the relevant literature, expected utility theory (EUT) has been used extensively to solve such problems. However, the application of Prospect Theory (PT) has demonstrated that people deviate from the expected utility maximization because their effective behaviors reflect loss aversion and risk-seeking, reflection effects. The aim of this paper was to compare and critically analyze EUT and PT with the goal of outlining the different behaviors of a "real" decision maker (DM) and an "ideal" DM, with the real DM operating in the frame of PT and the ideal DM operating as EUT describes. The results of using the two different theories were compared by solving three power-system problems in uncertain scenarios.

## 1. Introduction

Several problems in the analysis of power systems require making decisions under uncertainty. A traditional category, for example, includes the selection of optimal conductors, the selection of optimal routing for the new lines, and the selection of a substation transformer [1–3]. An additional new category of decision problems comprises issues that arise in unbundled electric power systems with the introduction of electricity markets. The examples that follow are illustrative without being exhaustive:

- installing generation plants for an independent power producer,
- sizing and locating embedded generation units in distribution systems (for example, see the recent papers [4,5]),
- optimizing the company's portfolio in electricity markets for sellers and for consumers (i.e., the problem of the optimal allocation of energy between spot and forward markets or between spot and bilateral markets),
- determining the optimal strategy for bidding in the spot market,
- planning distribution networks,
- selecting investments to improve power quality.

For all the above-mentioned decision problems, several factors, which sometimes are in conflict with each other, can influence the DM in characterizing the design alternatives; for instance, technical features as well as economic, regulatory, and political considerations should influence her/him.

Moreover, it is worth noting that most of the decision problems are affected by long- and short-term uncertainties; the various causes of uncertainty depend on the problem to be solved (load demand, the cost of energy, the spot price of energy, and the presence of congestion or outages). In [6], the authors exhaustively classified the methods that can be applied to handle with uncertainty.

EUT has been considered for several years as the dominant normative and descriptive model of decision making under uncertainty [1]. However, in this decision theory, the DM's behavior is practically never considered, even though several studies in the relevant literature have shown that human behavior has several psychological characteristics under risk and uncertainty [7–11]. Since decision-making problems in power systems are usually risky and uncertain, the behavioral aspects of the DM must be considered if effective decision support is to be provided in power systems.

PT was developed by Kahneman and Tversky in 1979 [7,8] as a theory that was able to describe how individuals make choices in situations in which they have to decide between alternatives that involve risk. In this theory, the DM's behavioral characteristics are considered extensively.

In particular, Kahneman and Tversky (and a myriad of other authors) demonstrated that individuals deviate from the expected maximization of the utility.

In more detail, first, PT replaces the concept of "utility" with "value", because utility is usually defined only in terms of net wealth, whereas value is defined in terms of gains and losses; these gains and losses are measured relative to a reference point, typically taken to be the *status quo*. Gains and losses are characterized

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by different value functions; in fact, the value function for losses is convex and relatively steep while, in contrast, the value function for gains (above the horizontal axis) is concave and not quite so steep. Finally, PT predicts that preferences will depend on how a problem is framed. If the reference point is defined such that an outcome is viewed as a gain, then the resulting value function will be concave, and decision makers will tend to be risk averse. However, if the reference point is defined such that an outcome is viewed as a loss, then the value function will be convex, and decision makers will be risk takers. As a result, PT differs from expected utility theory in a number of important respects.

The comparison of the PT and EUT theories provides some interesting observations about the two approaches. First, it is important to note that PT should not be considered a normative theory (i.e., to give optimal decisions). This is because it does not furnish necessarily the most useful solution of a decision problem. Even so, PT is a valuable tool because it furnishes information on the practical behavior of "real" DMs who operate without using any consolidated, decision-theory methodology.

The features of PT described in the previous paragraph can be particularly useful in power systems when (i) a DM must make decisions for problems that involve competitors, i.e., producers and consumers in competitive markets, whose behaviors and knowledge can help identify the best course of action and (ii) people (i.e., operators of transmission or distribution systems or national regulation operators) are interested in forecasting the future development of a system or a regulatory setting. In doing so, they wish to take into account that the actual development is the consequence of decisions mainly (if not uniquely) of "real" DMs. Also, the knowledge of PT solutions can be useful (i) for DMs to compare the own decisions with the EUT-based decisions of other DMs who have the same problem and (ii) in evaluating the future gap that can be incurred. Knowledge of the "real" DMs' decisions is indispensable when strategies are needed for improving the decision-making process.

In this paper, we proposed additional applications of PT to decision problems related to the planning and operation of power systems; in fact, PT already have been applied extensively to decision problems in several diverse areas, including economics, medicine, and science.

Recently, PT also has been applied to deal with some power system problems. A literature review is given in Section 2.

The main goals of this paper can be summarized as (i) to explore possible applications of PT for understanding the behavior of "real" power systems' DMs and (ii) to compare the decisions of "real" DMs, obtained by the PT, with the decisions of "ideal" DMs, which can be obtained by the normative model based on EUT. The purpose of the comparison was to verify that individuals deviate from the expected utility maximization owing to their effective behaviors of loss aversion and the effects of their risk-seeking.

To better finalize the theoretical considerations, three simple decision problems under uncertainty scenarios in power systems were analyzed by both PT and EUT. The case study proposed aimed (i) at evidencing, in a clear and straightforward way, the ease with which PT can be applied and (ii) at comparing the solutions obtained by the two theories.

Note that the choice of only comparing PT with EUT was based on the compelling need to provide a straightforward metric for an immediate measure of the gaps between the normative ideal and the descriptive reality. In future work, these two decision models will be compared with other decision models.

The paper is organized as follows. Section 2 summarizes the literature review. In Section 3, some basic concepts of decision theory are described, and some remarks about the EUT are given to provide a better understanding of the differences between EUT and PT, which are described in Section 4. In Section 5, three problems associated with power systems are formulated, and the results obtained with the PT application are compared with the results obtained by EUT. A detailed analysis of results is given in Section 6. Our main conclusions and recommendations for future work are presented in Section 7.

## 2. Application of PT to power systems problems: literature review

In spite of a myriad of papers [9] addressing applications of PT to various branches of economics and science, only recently has PT been applied to deal with power systems' problems.

In [12], PT was applied to obtain the bids of a generation company. This is defined as a process of risk decision-making, due to the high volatility of market prices and rivals' behaviors. The bidding of generation companies in a competitive market is considered also in [13], where the cumulative Prospect Theory is applied in modeling the bidding process to account for the fact that the generation companies are limited, rational, and risk-considering and that they have the final aim of acquiring more realistic bidding.

In [14], with reference to the capacity market in which suppliers can bid very high prices in the energy and ancillary markets to avoid operation and, then, over-offer in capacity markets, the PT has been applied to analyze the potential return and associated risk of the over-offering strategy, as well as their relationships with the factors that affect profitability. PT helps define a penalty mechanism that can make the cheating strategy less profitable and more risky for the potential cheaters to exercise.

A further domain of applications regards the investment decisions on renewable energy. In particular, [15] developed a conceptual model that examines the behavioral factors that affect investors' decisions, as well as the relationship between renewable energy investments and portfolio performance. The final aim of the model is to help policy makers design more effective policy instruments to support the market deployment of sustainable energy technologies.

In [16], the authors considered the issues related to the installation of smart meters and related technologies in homes as part of transforming the current electrical grid into a "smart grid". Achieving this transformation requires consumers to accept these new technologies and take advantage of the opportunities they create. In [16], methods from behavioral decision research were used to develop an understanding of consumers' beliefs about smart meters.

Recently, the cumulative PT has been applied also to the problem of capacity credit of wind power [17]. In particular, the analysis is based on the assumption that a decision maker will not have a neutral risk propensity towards changes to the outcome of the capacity credit and will discount increases and decreases of the loss of load expectation according to a non-linear preference; consequently, the capacity credit of wind power is valued according to a methodology that incorporates the non-linear preference.

## 3. The expected utility theory

In decision theory, it is common to summarize various unknown, extraneous factors into a number of cases (states of nature) with each one associated with a probability of occurrence. The possible outcomes of a decision are defined as the combined effect of a chosen alternative and the state of nature that it obtains. Once the decision alternatives and the states of nature are defined and the outcomes of all possible decisions are determined, all of this information can be represented by a decision matrix. The