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End user perceptions toward smart grid technology: Acceptance, adoption, risks, and trust

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ABSTRACT

Although smart grid technology has been extensively accepted, social factors influence the performance of smart grid systems. This smart technology will enable the automated monitoring and control of the power delivery system, increase the capacity of the power delivery system, and enhance the performance and connectivity of end users. However, the perceptions of end users are a key factor for adoption of this technology. When end users do not fully accept the smart grid, the operation of the smart grid is not satisfactory. Most literature has concentrated on the technological aspects of smart grids; a technological solution may be defined as one that requires a change only in the developed technology, demanding little or no change in human values or ideas of morality about the usage of electrical energy. However, the solutions to the problems of implementing smart grid technology are not to be found only in technological aspects. This paper presents experimental scenarios that use signal detection theory (SDT), a well-known tool in psychology research, to capture the perceptions of end users about smart grid technology. If the perceptions of end users are positive, the performance of the smart grid is improved. End user criteria can be analyzed using SDT. In addition, fuzzy logic type 2 is suggested as a way to increase the descriptive power of fuzzy signal detection theory. To obtain end user perceptions, several experimental scenarios were created using a didactic smart grid system designed by Delorenzo Group Italy. End users were faced with real situations that enabled determination of their perceptions about the smart grid technology. Experimental results of end users' perceptions of smart grid technology are shown using SDT, fuzzy detection theory, and fuzzy detection theory type 2. The results show that end users have a conservative criterion because they are not entirely confident in the intelligent technology provided by the smart grid; this conservative criterion limits smart grid performance.

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1. Introduction

A smart grid (SG) is an updated electrical system for managing electrical energy delivery from utility providers to end users. It allows end users to utilize information about their consumption patterns to make more informed decisions about their private consumption of electrical energy. The SG uses smart elements, called smart meters, to monitor energy consumption in real time. These next-generation smart metering systems are a revolutionary addition to existing power grids [36]. With the integration of advanced computing and communication technologies, end users can make informed decisions about renewable energy resources, electrical energy consumption, and distributed electrical grid intelligence [37]. Since smart meters have advanced features that allow consumers to track their energy consumption over short and long periods, they are considered an essential part of the solution for achieving energy efficiency and sustainable development in smart grids.

The smart grid is conceived of as an electric grid that can deliver electricity in a controlled, intelligent way from points of generation to active end users. End users and the SG require advanced computing and communication systems to respond to electrical demand. Promoting end user interaction and responsiveness offers a broad range of potential benefits for system operation and expansion and for market efficiency [38].

In general, the main features that make SGs different from conventional grids are the capacity for self-healing, active participation of all types of customers, accommodation of all generation and storage options, compliance with new markets that support both wholesale and retail electricity markets, resilience to attacks and natural disasters, and provision of enhanced power quality [12]. In addition to an understanding of consumer perceptions, expectations, and intentions, a complete understanding of end user values and norms is needed by SG policy makers and investors [39]. In February 2010, two-thirds (68%) of Americans had never heard the term “smart grid,” while 57% of adults in the U.S. were aware of how much electricity they were consuming and 67% said they would reduce their usage if they had the information needed to do so [44]. End user acceptance is directly connected with the perceived usefulness of a technology and is defined as the degree to which a person believes that using a particular technology would enhanced his life [45]. This concept can be applied to SGs [46].

The SG is a new concept that is different from existing power supply and energy distribution systems; the crucial differences are both technical and related to social acceptance. Some researchers have discussed how the new energy systems will be socially constructed and embedded [18,7], but, as presented by [40], consumer behavior is complex and rarely follows traditional economic theories of decision-making. When choosing what products to buy or what services to use, consumers believe they are making smart decisions and behaving in ways that are highly rational and congruent with their values and intentions. However, electrical energy consumers regularly diverge from rational decision-making, in which one objectively weighs the costs and benefits of all alternatives before selecting the optimal course of action.

This paper provides an analysis of the perceptions of end users on the basis of experimental results. Signal detection theory (SDT) and the concept of the “tragedy of the commons” are used to capture in a comprehensive fashion users' perceptions about SG technology. The first use of the “tragedy of the commons” is attributed to American ecologist Garrett Hardin, in his 1968 paper describing European farmers’ practice of sharing common land to graze their cattle [8]. It is in each herder’s interest to put all of his cows on the land, even if the quality of the commons is damaged through overgrazing. The individual receives all of the benefits from any additional cow put to graze, but damage to the commons is shared by the group [40]. The tragedy of the commons therefore refers to the depletion of a shared resource by individuals acting independently and rationally according to each person's self-interest, even while knowing that an abuse of the common resource is contrary to their individual long-term best interests. This concept can be perfectly applied to smart grid operations because end users have to share their individual benefits with society. Hence, the SDT evaluation described in this study included questions about benefits to society.

Global warming has been linked to the burning of crude oil and natural gas. Because SG technology helps increase the implementation of renewable energy in electric markets and alleviate the problem of global warming [47], it is a key technology for improving environmental and financial conditions for end users. In fact, end user perceptions are one of the main factors for a successful SG in which the end users are entirely motivated and involved in the energy concept. Since the perceptions of end users determine their criteria for acceptance of SG technology, it is important to understand end user perceptions in order to reach optimal conditions in the SG. The tragedy of the commons can occur in a SG when an end user increases his energy consumption and individual benefits (e.g., using more air-conditioning, operating home appliances during peak hours) and thereby diminishes the benefits to the group. When demand for electrical energy increases during peak hours, additional generating plants are needed to maintain power quality and eliminate voltage drops. However, construction of new generating plants is very expensive, so end users should be encouraged to aim for flat energy consumption during peak hours in order to keep the energy system in optimal conditions. Initiatives from utility providers may use promotions to manage energy consumption [5]. For example, when consumers are enabled by SG technology to use less electricity during peak hours, their electric bill is reduced. This leads consumers to shift their consumption to non-peak hours [17], and perceptions of SG technology improve.

Another problem arises when end users do not adopt renewable energy, a decision that has a direct environmental impact by increasing CO_2 emissions. In the SG commons, a large number of utilities are part of the community, but end users also play a key active role. The main problems in dealing with the world energy commons are not likely to be solved only with technical solutions [40]. Understanding the perceptions of end users is non-technical, but it is an important step toward successful SG operation. Consumer acceptance is a crucial factor of end user perceptions about SGs; as a result, end users are one of the main elements in SG deployment. However, the acceptance criteria of end users have not been thoroughly studied and considered in relation to SG implementation. This study therefore included experimental scenarios in which end users had to make crucial decisions while the SG was in operation. These scenarios directly affected perceptions about the world commons because end users were able to see how their decisions affected the commons.

The importance of SDT lies in the fact that it can deal in a clear manner with perceptions and the ways in which choices are made. This paper proposes the use of fuzzy logic type 2 to expand the potential of SDT and enhance understanding of the criteria of end users for using SG technology. Although fuzzy type 1 detection theory (FDT) allows for overlapping signals and a non-binary description of the final response, a complete representation of uncertainty is not possible, so fuzzy type 2 signal detection theory (FDT2) was used to model the uncertainties and noise conditions in SG perceptions. Highly motiving factors can attract end users to SG technology; thus, this paper discusses the main aspects of the end user decision process that are responsible for maintaining a balance between individual and societal SG benefits. End users in