Electrical Power and Energy Systems 99 (2018) 363–375

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Detection of illegal consumers using pattern classification approach combined with Levenberg-Marquardt method in smart grid

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ARTICLE INFO

Keywords:
Electricity theft
Non-technical losses
Probabilistic neural network (PNN)
Levenberg-Marquardt method
Energy consumption patterns

ABSTRACT

Detection of illegal consumers is an extremely challenging problem in smart grids as well as traditional environments. In a smart grid environment, electrical energy illegal customers can be divided into two types; (1) if the customer consumes all of its required energy in a portion of day illegally, (2) if the customer consumes a portion of its required energy illegally. Many methods about illegal consumption or electricity theft detection have been proposed but they are able to detect only one type of illegal consumptions. In this paper, a combined method is proposed to detect both two types of illegal consumptions. Customer energy consumption pattern classification method based on probabilistic neural network and mathematical model based on Levenberg-Marquardt method are used to detect the first and second type of illegal consumption, respectively. Moreover, the impact of Distributed Generation (DG) sources on illegal consumption of electricity is analyzed and proposed detection algorithm is modified to compensate it. Experimental results are presented to show the effectiveness of this method in detection of both two types of illegal consumption.

1. Introduction

Energy loss represents an economic loss for electricity companies, which is one of the main concerns in utility companies in smart grids as well as traditional environments. Energy losses are generally divided into two categories; Technical and non-technical losses (NTL) [1–3]. Technical loss is related to power flow dispatched in line, transformers and other power system components. It depends largely on the physical properties of the network, and its optimization is an engineering issue, involving classic tools of power systems planning and modeling. On the other hand, NTL is independent on the network physical properties and is caused by the factors external to distribution network. NTL is independent of the network physical properties, caused by the factors external to distribution network. There are several types of NTL such as electricity theft, deficiencies in the processes of energy measurement and unpaid bills. Electricity theft can be due to un-metered supply or diversity of readings. In particular, diversity of readings includes, but is not limited to, the causes such as meter tampering, bypassing meters by rigging lines from the power source, arranged false meter readings by bribing meter readers [4,5].

Although NTL is an avoidable financial loss for the utility, due to the lack of attention to the utility for the amounts of pilfered electricity by illegal costumers, energy consumed by illegal costumers is increased compared to energy consumed by legal costumers, because legal costumers adjust their consumption to their ability to pay for electricity services. This causes energy efficiency of Electricity Company to become more reduced. NTL not only rises the price in electricity charges but also influences many other factors such as inflation, unemployment, load-shading, disturbs routine of industries, factories and other businesses, rises debts of power energy companies, as well has a high impact on economical state of country [6] .

Total losses in distribution system have been reported to be 10–40% that only 3–5% of which is related to Technical losses [7,8]. Therefore, utilities lose huge cost every year due to NTL and they attempt to reduce this problem with the implementation of mechanisms.

In a smart grid environment, smart meters play an important role in monitoring the performance of the grid and the customer energy usage characteristics. Smart meters can provide customers with high quality real-time or near-real-time electricity consumption data. Collection of energy consumption data from all customers at regular intervals of time allows the utility to manage and optimize electricity demand more efficiently. In addition, energy consumption data can help utilities in detecting unauthorized consumption and electricity theft in view of improving the distribution efficiency and power quality. After implementation of a smart grid, tampering with the meter may be the predominant way of pilfering [7]. Therefore, in a smart grid environment, illegal consumers are classified into two groups; the first group has the null consumption during a certain period. They are stealing all

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https://doi.org/10.1016/j.ijepes.2018.01.036
Received 5 June 2017; Received in revised form 3 December 2017; Accepted 18 January 2018

consumption energy only in a portion of day. However, the other group steals a portion of their consumption energy. Thus, their consumption energy reading is lower than the consumption that they might have.

In this paper, a combined method is proposed to detect both two types of illegal consumptions. Initially, customer s energy consumption features are extracted by an encoding algorithm. Extracted features are then used in classification method based on probabilistic neural network (PNN) [9,10] to identify the first type of illegal consumer. Then, to identify the second type of illegal consumer, a mathematical model based on Levenberg-Marquardt [11,12] is used. Finally, the impact of Distributed Generation (DG) sources on illegal consumption of electricity is analyzed and modifying algorithm is presented.

The main original contributions of this paper are summarized as Follows:

- The proposal of an algorithm to detect both two types of illegal consumptions in smart grid.
- The proposal of an efficiency classifying method based on probabilistic neural network and number of abnormalities in energy consumption data of consumers to detect customers that consume all of their required energy in a portion of day illegally.
- The proposal of a mathematical model based on Levenberg-Marquardt to identify consumers that consume portions of their required energy illegally.
- Modifying the proposed algorithm to detect illegal consumers in presence of DG.

The remainder of this paper is organized as follows: Section 2 completes a brief literature survey. Analyzing energy consumption patterns is presented in Section 3. In Section 4 the framework of proposed methodology for electricity theft detection is proposed. The first type of electricity theft detection using customer energy consumption patterns classification is described in Section 5. In Section 6, detecting the second type electricity theft using mathematical model based on Levenberg-Marquardt method is explained. Impact of technical loss estimation error on proposed method is discussed in Section 7. Modified proposed detection algorithm is presented in Section8 8 to compensate the impact of DG on illegal consumers. Section 9 discusses the experiments, and Section 10 states conclusions.

2. Previous work

There are many factors that influence consumers to steal electricity such as social, political, economic, literacy, law, managerial, infrastructural, and economical ones. Of these factors, socio-economic factors influence people to a greater extent in stealing electricity. It is important to pay attention to this point that electricity theft is a non-technical problem and to solve it, non-technical as well as technical techniques should be utilized. Therefore, proposed techniques in literatures can be divided into two categories; electricity theft detection technical (ETDT) methods and electricity theft detection non-technical (ETDNT) methods. Several ETDNT methods that has been and can be done include:

- Inspection and detection of illegal consumers of electricity by teams who reward depends on the number of cases they inspect [13].
- Giving information to the consumers about crime and punishment related to electricity theft.
- Installing the meters in a place that is not easily manipulated by consumers.
- Reducing electricity theft using psycho-social methods.

In addition, several ETDNT methods are proposed in literatures [14–25]. These methods can be classified into three groups; Physical methods [14–16], methods based on Artificial Intelligence [17–22] and methods based on system modeling [22–25].

Utility companies are not tending to use physical methods because the implementation of physical methods is very expensive and the equipment used will need to be repaired periodically. Therefore physical methods are more focused on planning goals. The second group of previous methods have used artificial intelligence techniques to detect electricity theft. Over the past years, methods based on artificial intelligence have become more popular. The most commonly used methods are support vector machines and neural networks, which outperform expert systems in most settings. In [5], the six main open challenges in NTL detection methods based on artificial intelligence have been identified. One of these challenges is “describing features from the data”. The methods based on artificial intelligence are typically applied to features computed from customer consumption profiles and require the feature extraction from historical data for training process. To remedy this defect, an encoding technique has been proposed in [20–22] that simplifies the received customer energy consumption readings and maps them into corresponding irregularities in consumption.

Then, irregularities or discrepancies in customer energy consumption have been used to classify genuine and illegal consumers. However, parameters regulation in the second stage of proposed algorithm is very difficult and accuracy of the obtained conclusion is less. Thus, only the first stage of proposed algorithm can be efficiently used to detect the first type of electricity theft. Other group of previous methods has used mathematical model to detect electricity theft. In [23,24] a method based on adversary’s behaviors mathematical model has been used to detect electricity theft. This method is only efficient to detect illegal consumers whose consumption energy reading is lower than their actual consumption energy by tampering their meters. In [25] two linear regression-based algorithms have been proposed to identify of energy theft and defective smart meters in smart grids. However, capability of detecting the first type of electricity theft has not been studied for this method. To address some of the limitations of previous work, a combined method is proposed to detect both two types of electricity theft are proposed in this work.

3. Analyzing energy consumption patterns

Utility companies understand the condition of grid and energy consumption behavior of customers by analyzing customer energy consumption patterns. Dependent on the range of the customer, geographical location, time of the day, season of the year and weather conditions, energy consumption data from a customer varies from time-to-time over a day.

In smart grid environment, energy consumption data of all customers is recorded in the 15-min intervals, i.e. a total of 96 times a day. These data can help utilities to detect unauthorized consumption and electricity theft. Fig. 1 represents three energy consumption readings of the same customer for the following three cases:

Legal consumption: if the same customer consumes energy required entirely legally;

The first type of illegal consumption: if the customer consumes all of its required energy in a portion of day illegally;

The second type of illegal consumption: if the customer consumes a portion of its required energy illegally.

The illegal consumptions can be also called the first type of electricity theft and the second type of electricity theft, too. It is important to pay attention to this point that the value of ratio of recorded energy by meter to the actual consumed energy in the second type of illegal consumption profile is not constant as shown in Fig. 1. As seen from this