DETECTING ELECTRICITY THEFT IN SMART GRIDS USING DEEP NEURAL NETWORKS

[1]M. VINAY KUMAR, [2]KATTUBADI SHAIK AMEENUDDIN
[1]Assistant Professor, [2]MCA Student
Department of Master of Computer application
Rajeev Gandhi Memorial College of Engineering and Technology
Nandyal, 518501, Andhra Pradesh, India.

ABSTRACT

Electricity theft is a global problem that negatively affects both utility companies and electricity users. It destabilizes the economic development of utility companies, causes electric hazards and impacts the high cost of energy for users. The development of smart grids plays an important role in electricity theft detection since they generate massive data that includes customer consumption data which, through machine learning and deep learning techniques, can be utilized to detect electricity theft. This paper introduces the theft detection method which uses comprehensive features in time and frequency domains in a deep neural network-based classification approach.We address dataset weaknesses such as missing data and class imbalance problems through data interpolation and synthetic data generation processes. We analyze and compare the contribution of features from both time and frequency domains, run experiments in combined and reduced feature space using principal component analysis and finally incorporate minimum redundancy maximum relevance scheme for validating the most important features. We improve the electricity theft detection performance by optimizing hyper parameters using a Bayesian optimizer and we employ an adaptive moment estimation optimizer to carry out experiments using different values of key parameters to determine the optimal settings that achieve the best accuracy. Lastly, we show the competitiveness of our method in comparison with other methods evaluated on the same dataset. On validation, we obtained 97% area under the curve (AUC), which is 1% higher than the best AUC in existing works, and 91.8% accuracy, which is the second-best on the benchmark.

1. INTRODUCTION

ELECTRICITY theft is a problem that affects utility companies worldwide. More than $96 billion is lost by utility companies worldwide due to Non-Technical Losses (NTLs) every year, of which electricity theft is the major contributor [1]. In sub-Saharan Africa, 50% of generated energy is stolen, as reported by World Bank [2].

The ultimate goal of electricity thieves is to consume energy without being billed by utility companies [3], or pay the bills amounting to less than the consumed amount [4]. As a result, utility companies suffer a huge revenue loss due to electricity theft. [5] reports that in 2015, India lost $16.2 billion, Brazil lost $10.5 billion and Russia lost $5.1 billion. It is estimated that

approximately $1.31 billion (R20 billion) revenue loss incurred by South Africa (through Eskom) per year is due to electricity theft [2].

Apart from revenue loss, electricity theft has a direct negative impact on the stability and reliability of power grids [3]. It can lead to surging electricity, electrical systems overload and public safety threats such as electric shocks [4]. It also has a direct impact on energy tariff increases, which affect all customers [3]. Implementation of smart grids comes with many opportunities to solve the electricity theft problem [4]. Smart grids are usually composed of traditional power grids, smart meters and sensors, computing facilities to monitor and control grids, etc., all connected through the communication network [6]. Smart meters and sensors collect data such as electricity usage, grid status, electricity price, etc. [6]. Many Utilities sought to curb electricity theft in traditional grids by examining meters' installation and configurations, checking whether the power line is bypassed, etc. [4]. These methods are expensive, inefficient and cannot detect cyber-attacks [4], [7]. Recently, researchers have worked towards detecting electricity theft by utilizing machine learning classification techniques using readily available smart meters data. These theft detection methods have proved to be of relatively lower costs [8]. However, existing classification techniques consider time-domain features and do not regard frequency-domain features, thereby limiting their performance.

Regardless of the fact that there is active ongoing research on electricity theft detection, electricity theft is still a problem. The major cause of delay in solving this problem may be that smart grids deployment is realized in developed nations while developing nations are lagging behind [9]. The challenges of deploying smart grids include the lack of communication infrastructure and users' privacy concerns over data reported by the smart meters [10]. However, [10] reports that smart meters are being considered by many developed and developing countries with aims that include solving NTLs. [11] predicted smart grids global market to triple in size between 2017 and 2023, with the following key regions leading smart grids deployment: North America, Europe and Asia.

In this paper, we present an effective electricity theft detection method based on carefully extracted and selected features in Deep Neural Network (DNN)-based classification approach. We show that employing frequency-domain features as opposed to using time-domain features alone enhances classi_cation performance. We use a realistic electricity consumption dataset released by State Grid Corporation of China (SGCC) accessible at [12]. The dataset consists of electricity consumption data taken from January 2014 to October 2016.

The main contributions are as follows:
_ Based on the literature, we propose a novel DNN classification-based electricity theft detection method using comprehensive time-domain features. We further propose using

frequency-domain features to enhance performance.

_ We employ Principal Component Analysis (PCA) to perform classification with reduced feature space and compare the results with classification done with all input features to interpret the results and simplify the future training process.

_ We further use the Minimum Redundancy Maximum Relevance (mRMR) scheme to identify the most significant features and validate the importance of frequency-domain features over time-domain features for detecting electricity theft.

_ We optimize the hyper parameters of the model for overall improved performance using a Bayesian optimizer. We further employ an adaptive moment estimation (Adam) optimizer to determine the best ranges of values of the other key parameters that can be used to achieve good results with optimal model training speed.

_ Lastly, we show 1% improvement in AUC and competitive accuracy of our model in comparison to other data-driven electricity theft detection methods in the literature evaluated on the same dataset.

The remainder of this paper is organized as follows. Section II covers the related work done in literature to tackle the electricity theft problem. In Section III, we briefly introduce techniques used in this paper. Section IV covers step by step method taken in this work; which includes dataset analysis and work done to improve its quality and customers' load profile analysis which lead to features extraction and classification. In Section V, we show and discuss the results. We conclude the paper in Section VI. Many Utilities sought to curb electricity theft in traditional grids by examining meters' installation and con_gurations, checking whether the power line is bypassed, etc. [4].

These methods are expensive, inefficient and cannot detect cyber attacks [4], [7]. Recently, researchers have worked towards detecting electricity theft by utilizing machine learning classification techniques using readily available smart meters data. These theft detection methods have proved to be of relatively lower costs [8]. However, existing classification techniques consider time-domain features and do not regard frequency-domain features, thereby limiting their performance.

2. LITERATURE STURVEY

‘‘An alternative technique for the detection and mitigation of electricity theft in South Africa,’

Electricity theft and illegal connection by ground surface conductors is a pervasive problem in South Africa. The impact this phenomenon has is not only limited to revenue loss and equipment damage, but also presents a life threatening hazard. Although the issues of non-technical losses have been researched for decades, no universal solution has been presented, due to the complexity of the problem. This paper investigates the application of zero-sequence current-based detection as a mitigation strategy to deal with illegal connections by ground surface conductors. Simulation and experimental results show the validity of this technique as well as its dependence on seasonal change of the soil resistivity.

‘‘Electricity theft detection using pipeline in machine learning,’’

Electricity theft is the primary cause of electrical power loss that significantly affects the revenue loss and the quality of electrical power. Nevertheless, the existing methods for the detection of this criminal behavior of theft are diversified and complicated since the imbalanced nature of the dataset, and high dimensionality of time-series data make it challenging to extract meaningful information. This paper addresses these problems by developing a novel electricity theft detection model, integrating three algorithms in a pipeline. The proposed method first applies the synthetic minority oversampling technique (SMOTE) for balancing the dataset, secondly integration of kernel function and principal component analysis (KPCA) for the feature extraction from high dimensional time-series data, and support vector machine (SVM) for the classification. Besides, the performance of the proposed pipeline is measured using a comprehensive list of performance metrics. Extensive experiments are performed by using real electricity consumption data, and results show that the proposed method outperforms other methods in terms of theft detection.

‘‘Wide and deep convolutional neural networks for electricity-theft detection to secure smart grids,’’

Electricity theft is harmful to power grids. Integrating information flows with energy flows, smart grids can help to solve the problem of electricity theft owning to the availability of massive data generated from smart grids. The data analysis on the data of smart grids is helpful in detecting electricity theft because of the abnormal electricity consumption pattern of energy thieves. However, the existing methods have poor detection accuracy of electricity theft since most of them were conducted on one-dimensional (1-D) electricity consumption data and failed to capture the periodicity of electricity consumption. In this paper, we originally propose a novel electricity-theft detection method based on wide and deep convolutional neural networks (CNN) model to address the above concerns. In particular, wide and deep CNN model consists of two components: the wide component and the deep CNN component. The deep CNN component can accurately identify the nonperiodicity of electricity theft and the periodicity of normal electricity usage based on 2-D electricity consumption data. Meanwhile, the wide component can capture the global features of 1-D electricity consumption data. As a result, wide and deep CNN model can achieve the excellent performance in electricity-theft detection. Extensive experiments based on realistic dataset show that wide and deep CNN model outperforms other existing methods.

3. EXISTING SYSTEM

Hardware-based methods [13]_[19] generally require hardware devices such as specialized microcontrollers, sensors and circuits to be installed on power distribution lines. These methods are generally designed to detect electricity theft done by physically tampering with distribution components such as distribution lines and electricity meters. They can not detect cyber attacks. Electricity cyber attack is a form of electricity theft whereby energy consumption data is

modified by hacking the electricity meters [7].

For instance, in [13], an electricity meter was re-designed. It used components that include: a Global System for Mobile Communications (GSM) module, a microcontroller, and an Electrically Erasable Programmable Read-Only Memory (EEPROM). A simulation was done and the meter was able to send a Short Message Service (SMS) whenever an illegal load was connected by bypassing the meter. Limited to detecting electricity theft done by physically tampering with distribution components such as distribution lines and electricity meters. Authors in [16] used the GSM module, ARM-cortex M3 processor and other hardware components to solve the electricity theft problem done in the following four ways: bypassing the phase line, bypassing the meter, disconnecting the neutral line, and tampering with the meter to make unauthorized modifications. A prototype was built to test all four possibilities. The GSM module was able to notify with SMS for each theft case.

Authors in [17] designed ADE7953 chip-based smart meter which is sensitive to current and voltage tempering, and mechanical tempering. ADE7953 was used to detect overvoltage, dropping voltage, overcurrent, the absence of load and other irregularities in voltage and current. It sent an interrupt signal to the Microcontroller Unit (MCU) which reported tampering status. Mechanical tampering was overcome by connecting a tampering switch to MCU's IO ports so that it can send alarm signals to MCU once tampered with. The design was tested with tampering cases such as
connecting the neutral and the phase lines, connecting the meter input and output in reverse mode, and bypassing the phase line to load. The probability of detection failure was 2.13%.

Authors in [15] used a step down transformer, voltage divider circuit, microchip and other hardware components to design a circuitry to detect electricity theft by comparing forward current on the main phase line with reverse current on the neutral line. The circuitry was installed before the meter.The design was tested on Proteus software and on actual hardware. When the meter was bypassed, the problem was detected and an alarm sounded. In [14], a circuit to detect electricity theft done by bypassing the meter was designed. The transformers, rectifiers, microcontroller, GSM module and other hardware components were used. The GSM controller notified the operator with SMS when the meter was bypassed.

Disadvantages

- An existing system not implemented DNN-BASED ELECTRICITY THEFT DETECTION METHOD.
- An existing system not implemented Hyperbolic tangent activation function.

4. PROPOSED SYSTEM

_ Based on the literature, we propose a novel DNN classification-based electricity theft detection method using comprehensive time-domain features. We further propose using

frequency-domain features to enhance performance.

_ We employ Principal Component Analysis (PCA) to perform classification with reduced feature space and compare the results with classification done with all input features to interpret the results and simplify the future training process.

_ We further use the Minimum Redundancy Maximum Relevance (mRMR) scheme to identify the most significant features and validate the importance of frequency-domain features over time-domain features for detecting electricity theft.

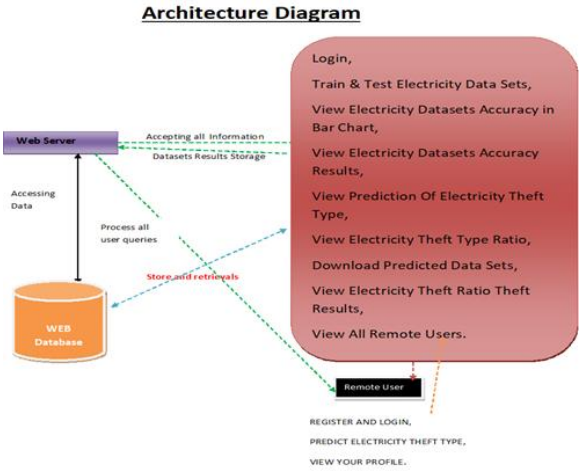
_ We optimize the hyper parameters of the model for overall improved performance using a Bayesian optimizer. We further employ an adaptive moment estimation (Adam) optimizer to determine the best ranges of values of the other key parameters that can be used to achieve good results with optimal model training speed.

_ Lastly, we show 1% improvement in AUC and competitive accuracy of our model in comparison to other data-driven electricity theft detection methods in the literature evaluated on the same dataset.

Advantages

- Huge amount of data obtained by cloud providers and other businesses, making large datasets that train DNNs effectively.
- Advances in machine learning and signal/information processing research which leads to the evolution of techniques to improve accuracy and broaden the domain of DNNs application.

5. SYSTEM ARCHITECTURE



6. IMPLEMENTATION

MODULES:

Service Provider

In this module, the Service Provider has to login by using valid user name and password. After login successful he can do some operations such as Login, Train & Test Electricity Data Sets, View Electricity Datasets Accuracy in Bar Chart, View Electricity Datasets Accuracy Results, View Prediction Of Electricity Theft Type, View Electricity Theft Type Ratio, Download Predicted Data Sets, View Electricity Theft Ratio Theft Results, View All Remote Users. View All Remote Users.

View and Authorize Users

In this module, the admin can view the list of users who all registered. In this, the admin can view the user's details such as, user name, email, address and admin authorizes the users.

Remote User

In this module, there are n numbers of users are present. User should register before doing any operations. Once user registers, their details will be stored to the database. After registration successful, he has to login by using authorized user name and password. Once Login is successful user will do some operations like REGISTER AND LOGIN, PREDICT ELECTRICITY THEFT TYPE,VIEW YOUR PROFILE

7. CONCLUSION AND FUTURE ENHANCEMENT

In this work, the detection of electricity theft in smart grids was investigated using time-domain and frequency-domain features in a DNN-based classification approach. Isolated classification tasks based on the time-domain, frequency domain and combined domains features were investigated on the same DNN network. Widely accepted performance metrics such as recall, precision, F1-score, accuracy, AUCROC and MCC were used to measure the performance of the model. We observed that classification done with frequency-domain features outperforms classification done with time-domain features, which in turn is outperformed by classification done with features from both domains.

The classifier was able to achieve 87.3% accuracy and 93% AUC-ROC when tested. We used PCA for feature reduction. With 7 out of 20 components used, the classifier was able to achieve 85.8% accuracy and 92% AUC-ROC when tested. We further analyzed individual features' contribution to the classification task and confirmed with the MRMR algorithm the importance of frequency-domain features over time-domain features towards a successful classification task. For better performance, a Bayesian optimizer was also used to optimize hyper parameters, which realized accuracy improvement close to 1%, on validation. Adam optimizer was incorporated and optimal values of key parameters were investigated.

In comparison with other data-driven methods evaluated on the same dataset, we obtained 97% AUC which is 1% higher than the best AUC in existing works, and 91.8% accuracy, which is the second-best on the benchmark. The method used here utilizes consumption data patterns. Apart from its application in power distribution networks, it can be used in anomaly detection applications in any field. Our work brings a small contribution towards accurately detecting energy theft as we detect theft that only took place over time. We wish to extend our method to detect real-time electricity theft in the future. Since this method was evaluated based on consumption patterns of SGCC customers, it can further be validated against datasets from different areas to ensure its applicability anywhere.

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