

Non-Technical Losses in Power System: A Review

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Abstract—Utilities experience significant revenue fatalities due to Non-Technical Losses (NTLs). These losses are principally caused by fraud activities deliberately performed by the consumers. NTLs lead to a series of additional losses, including damage to grid infrastructure and reduction of grid reliability. This paper presents a rigorous review of technologies, methodologies and active approaches aimed at improving with emphasis in the accurate estimation and reduction of NTLs. Additionally, the sources of NTLs along with the possible impacts of NTLs on the economy is also focused.

Keywords—Classification;distribution system;non-technical losses; load profiles; power losses;theft of electricity

I. INTRODUCTION

PER capita electric power consumption of a country is often considered as an indicator of its socio economic condition. It is essential for uplifting the lifestyle of general people as well as industrial and agricultural development [1]. Power is one of the finest incarnations of early times, which is exploited by mankind through various ailing means, where theft of electricity (TOE) plays an imperative role. In many countries economic growth is hampered by inadequate and irregular supplies of electric power due to TOE [2]. Where power is scarce, firms and agricultural enterprises may offer bribes to government officials to divert electricity illegally, or they may opt out of public sector energy delivery and install their own power generators. If it is extensive, collusion between government, industry and agriculture provides a political incentive to keep electricity supplies inadequate so that government officials may continue to collect bribes [2], [3]. Merely generating more power is not enough to meet present day requirements. Power consumption and losses have to be closely monitored so that the generated power is utilized in an efficient manner. This paper presents a rigorous study about the nature of NTLs, sources, possibly their impact on the economy and diagnostic techniques of NTLs considered by numerous power utilities.

A. Methods of Non-technical losses

NTLs are mainly related to electricity theft and customer management processes in which there exist a number of means of consciously defrauding the utility concerned [2-4]. In most developing countries, transmission and distribution losses account for a tremendous portion of NTLs, which implies that electric utilities have to concentrate on reducing NTLs prior to reducing technical losses [5]. NTLs include the following activities [2-14]:-

- Tampering with energy meters to ensure the meter recorded comparatively lower consumption reading.
- Tapping of wires on LT lines.
- Errors in technical losses computation.

- Arranging false readings and ignoring unpaid bills by bribing meter readers.
- Un-metered supply.
- Errors and delay in meter reading and billing.

Directly connecting an unregistered load to a power line and tampering with a registered load's meter in order to reduce the size of the bill [2-14]. Once the meter seals are broken, there are many things that can be done to the meter to slow or stop it. As NTLs cannot be computed and measured easily, but it can be estimated from preliminary results, i.e. the result of technical losses are first computed and subtracted from the total losses for the estimation of NTLs [4],[5],[8],[15].

$$NTLs = Total\ losses - Technical\ losses \quad (1)$$

The technical losses are computed using appropriate load-flow studies simulated under MATLAB environment. Reduction of NTLs is crucial for distribution companies. As the classical method of dealing with NTLs imposes high operational costs due to onsite inspection by employees of the firm and requires extensive use of human resources [4]. Therefore, it is important to make effort to design new and effective techniques aims to reduce operational costs in monitoring NTL activities.

B. Effects of NTLs on Economy

In India electricity theft leads to annual losses estimated at US\$4.5 billion, about 1.5 percent of GDP [10]. The problem of NTLs is not only faced by the least developed countries in the Asian and African regions, but also by developed countries such as the United States of America and the United Kingdom [11], [16]. Explicitly, high rates of NTL activities have been reported in the majority of developing countries in the Association of South East Asian Nations (ASEAN) group, which include Malaysia, Indonesia, Thailand, Myanmar and Vietnam [11]. In 2004, Tenaga Nasional Berhad (TNB) Sdn. Bhd. the prime electricity provider in Malaysia recorded revenue loss of about USD 229 million a year as a result of NTLs [5], [8], [17].

The Andhra Pradesh State Electricity Board (INDIA), a government-owned vertically integrated power utility serving about 12 million customers, suffered large and growing financial losses in the 1990s, was adding up to US\$0.9 billion by 1997 due to NTLs [10]. A draft from World Bank [10], [13] report describes the performance of the utilities in Sub-Saharan countries. The median utility in that region presents huge inefficiencies. Only 50 percent of electricity generated is paid for, due to a combination of low percentages of amounts of electricity injected in distribution networks being billed and low rates of collection of the billed amounts [13]. The variation in performance is massive, with the

highest inefficiencies in Nigeria, where the utility is capturing only 25 percent of the revenues owed. Some studies have shown that hidden costs of distribution losses in Sub-Saharan Africa are usually more than 0.5 percent of GDP, and may be as large as 1.2 percent of GDP in some countries [10], [13].

II. LITERATURE BASED ON DIAGNOSTIC TECHNIQUES FOR NTLs

Diagnosis of NTLs is not a new focus of research. It will take more than ten decades of research to find out diverse and appreciable methodologies to diagnose the TOE up to an extent. Measures for the protection from TOE come into existence when in 1899, the Association of Edison Illuminating Companies (AEIC) indicated that electricity theft was a concern early on and it may be more vital in near future, in response to the recommendations proposed by the committee of the AEIC which incorporated some improvements like a frame of energy meter was so shaped to minimize curious tampering with the internal mechanism [18]. General Electric I-70S in 1968 and Schlumberger J5S in 1984 are the modern meters which having features proposed by AEIC [18]. The development of these meters, technological up gradation and alternative designs imitate the rising power industry in the late 19th century.

TABLE I. Diagnostic Techniques of NTLs in Literature

References	Findings
[19]	<ul style="list-style-type: none"> DSP based electricity meter system with multi-user and automatic meter reading capability. Automatic meter reading capability minimizes the manipulation in meter reading.
[20]	<ul style="list-style-type: none"> New non-supervised classification method to identify more meaningful variable, responsible to signify customer power consumption pattern effectively.
[14]	<ul style="list-style-type: none"> Introduce a remote check meter and concluded that data collection infrastructure and data mining software along with check meter are useful to identify and minimize TOE.
[4]	<ul style="list-style-type: none"> The intent of this study is to use the load profiling methods and data mining techniques to classify, detect and predict NTLs in the distribution sector.
[12]	<ul style="list-style-type: none"> A new computational techniques extreme learning machine (ELM) is introduced. Approach provides a method of data mining for this purpose, and it involves extracting patterns of customer behaviour from historical power consumption pattern.

A. Detection of Electricity Theft Using Genetic Algorithm SVM (GA-SVM) and SVM

J.Nagi et al. in [17] proposed a hybrid approach for the analysis of NTLs by using GA-SVM. Author got the motivation for this research study from TNB in Malaysia. This study uses historical customer data from TNB distribution (TNBD) Sdn. Bhd. Feature extraction method was used for load profiles in conjunction with

SVM. Initially customer consumption patterns are extracted by using data mining techniques which represents the load profile of customers [17]. It is assumed by default that load profiles contain abnormalities when a theft event occurs [17]. SVM classifies load profile of customers for detection of fraud suspects. SVMs were introduced by V.N Vapnik in the late 1960s [21]. Statistical learning theory is the foundation of SVM. SVM algorithm is basically used for classification and regression.

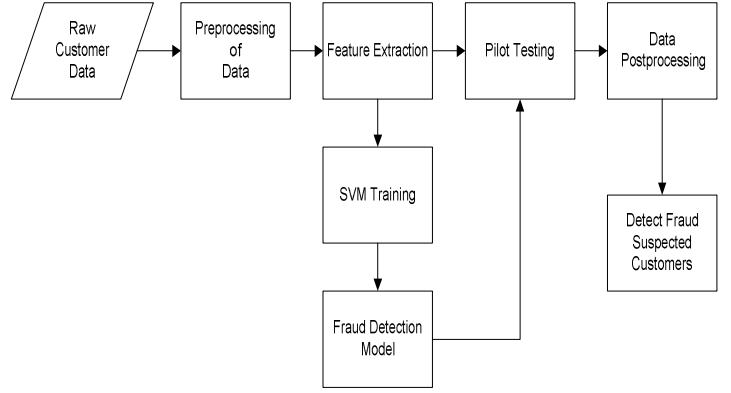


Figure 1 Framework for fraud electricity customer detection using GA-SVM [17]

Proposed framework work with historical data of 265,870 customers during a period of about 25 months and after customer filtering and selection 25 features are extracted from the data set for SVM classifier. It is observed that a hit-rate of 22% is achieved when onsite checking is performed by TNBD on the total number of customers short listed by fraud detection model. In order to improve the hit-rate another fraud detection model using SVM was explained in [5]. This analysis consider the same data set use in [17] having 25 features, but comparatively improved hit-rate of 26% is obtained in this approach. A decision making system utilizing structured query language (SQL) was implemented in the data post processing stage of the FDM to improve the detection hit-rate of the FDM [5]. By using the decision making system, the detection hit-rate results improved from 26% to 64%.

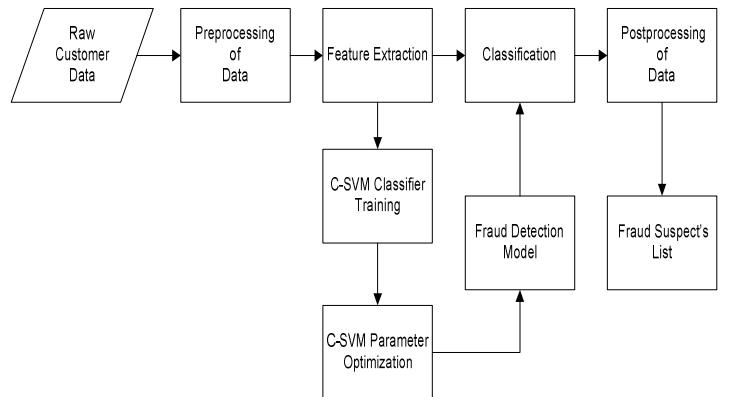


Figure 2 Framework for the detection of customers with abnormalities and fraud activities using SVM [5]

$$\text{Hitrate} = \frac{S_{fc}}{S_c} \times 100\% \quad (1)$$

where, S_{fc} represents the number of samples correctly classified as fraud cases by the C-SVM classifier and categorized as fraud cases by TNBD and S_c represents the total number of samples classified as fraud cases by the C-SVM.

B. Advance Meter Infrastructure

It is reported that the most faulty sub system in a distribution system is the metering and meter reading system. As Billing systems are discrete, inaccurate, costly, slow, traditional and less reliable, attempts were made to automate the billing systems. Error in energy billing get introduced at every stage of energy billing like errors with electro-mechanical meters, human errors while noting down the meter reading and error while processing the paid bills and the due bills [2-14]. The remedy for this drawback is Advanced Metering Infrastructure (AMI).

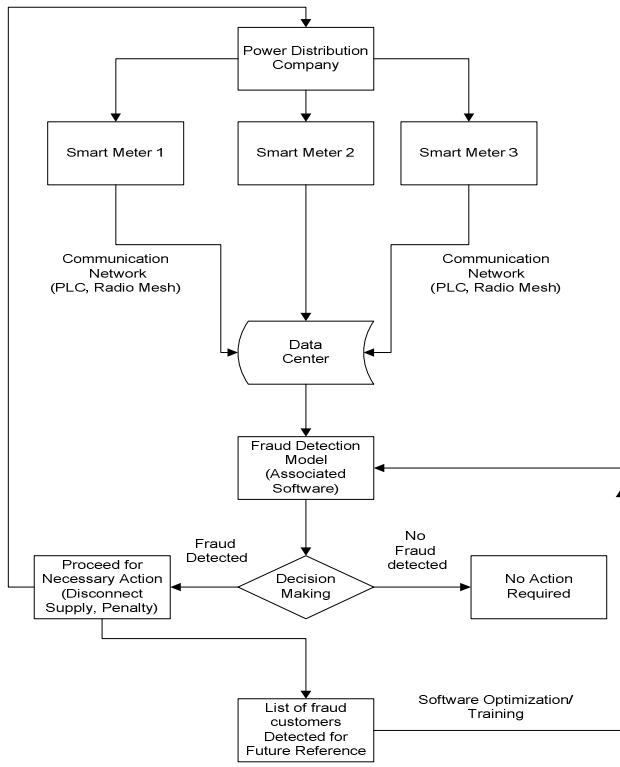


Figure 3 Distribution network using AMI methodology

AMI provides technical tools that reduce NTLs losses. AMI can provide power consumption readings that are difficult to influence with intrinsic theft and fraud detection mechanisms. In figure 3 distribution of power by using AMI methodology is showcased. Where the smart energy meters are connected to the distribution utility and the power consumption reading at the customer is collected at the data centers through various communication networks like PLC or radio mesh. The data collected at the data centre are analysed through several dedicated software based on unswerving fraud detection models. On the basis of analysis results required decision is executed.

Addition of AMI services like prepaid billing and remote check meter resolves the problem of unpaid bills [22]. Commercially prepaid energy meters are provided by various companies in the world market having their own features and reliabilities, but in [23] AVR microcontroller based pre-paid energy meter was proposed. The basics advantage of this approach is that by performing small modifications on the already installed meters can make it prepaid energy meter which in turn reduce the installation cost of new prepaid meter for power distribution Company.

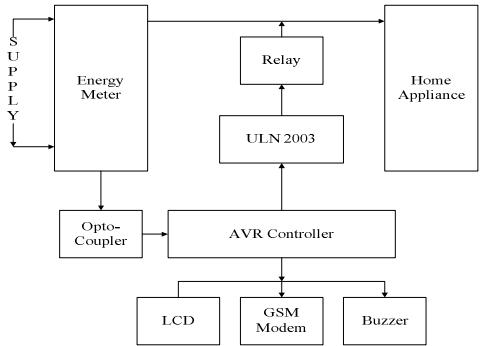


Figure 4 AVR microcontroller based prepaid energy meter [23]

Figure 4 shows the block diagram of AVM based prepaid energy meter. An AVR based pre-paid energy meter utilizes the features of embedded system which is the combination of hardware and software. By introducing GSM modem one can recharge the energy meter with the help of mobile. LCD displays the value of electricity that a customer can use. If the amount falls below certain minimum value then it can be indicated with the help of buzzer. Whenever the number of units (credit) in microcontroller becomes zero microcontroller sends a signal to the relay and this relay cut-off the supply to the consumer until next unit recharge [23].

Now days many developed and developing countries showing their interest for adopting prepaid energy system. West-Bengal an Indian state has decided for the installation of prepaid energy meter in remote islands of Sunder bans. In Mumbai prepaid power is provided by Brihanmumbai electric supply and transport (BEST) undertaking.

III. SUGGESTIONS TO MINIMIZE NTLs

There are following suggestions which might be effective to minimize the NTLs:-

- Statically monitoring of energy consumption per sector, per class and geographical setup must be employed.
- Static evaluation of meter readings must be done.
- Smart grid and smart metering are used in conjunction to minimize the theft.
- Integrated billing system and online prepaid energy meters are the choices which can be used for effective results.
- Technical training and loyalty learning sessions for the operating personnel and employees of power utility firms to enhance the technical knowledge as well as the loyalty.
- Awareness among customers about strict laws that can be used against them if they detect during theft of electricity.

- Price discounts in addition to regular discounts should be offered for customers who were willing to pay the electricity in advance.
- For strengthening the regular onsite check-up mechanism of theft detection, incentives are provided for utility staff.
- Strict legal reforms are required, so that the utilities have multiple options of punishing the offender's in-spite of disconnection or penalty only.
- Special prominence should be given to the theft detection equipment manufacturing companies. This will attract more manufacturing firms to invest in this field which in-turn increase the completion and reduce equipment cost.

IV. CONCLUSION

An attempt has been made in this paper to present a rigorous review of the sources, diagnostic techniques for NTLs and the socioeconomic consequences behind these losses. No single method can be considered as the best method for detecting NTLs. But prepaid energy meter gain incredible popularity among the power distribution companies as well as the customers, but still some efforts have to be done to make pre-paid energy meter more users friendly. However, advancement in technologies with better computational and statistical approaches can help to invent more efficient and striking techniques in near future.

With a growing economy, increase in power generation is not only the solution to accomplish the demand of power supply, when it is observed that most of the power generation resources like coal are at their extinct stage. The cost of establishing a new power generating unit is comparatively very high with the cost of equipment requires for minimizing the losses. For a developing economy it is important for power utilities to concentrate on non-technical loss reduction instead of reducing technical losses only, because the definite estimation of NTLs are responsible to predict the actual amount of power need to be generated in the near future to complete their demands. Reducing these losses ensure that the cost of electricity to customers will be reduced and in turn the efficiency of the distribution network will be improved.

V. SCOPE OF FUTURE WORK

NTLs in all forms are very real and momentous problem for power utilities. Remote monitoring system and prepaid energy meters are the choices which can be adopted by the distribution utilities for minimizing the gap between the cost of power distributed in the distribution network and the revenue generated from the actual billing. Some modifications can be done with prepaid energy meters may make it more user friendly. For instance if pre-paid energy meter have the swipe card feature then a user easily can recharge for the power credit unit at any time with the help of their credit cards.

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