An Approach to Determine Non-Technical Energy Losses in India

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***Abstract*—Electricity losses during transmission and distribution are extremely high in India. One of the principal reasons for this is the presence of non-technical energy losses (NTL), that is, energy losses caused due to theft, meter malfunction, etc. Identifying non-technical energy losses is an open research problem and various methods are being proposed to deliver an optimal solution for the same. The efficacy of any solution depends on the ability to customize it to the infrastructure available at the location of deployment. This paper presents a new methodology based on smart metering and advanced communication protocols to identify NTL due to theft as well as tampered or malfunctioning meters, considering the infrastructure and economy of India. Also, an analysis some of the existing methods/practices is done, and their feasibility in the Indian power sector is discussed.**

Keywords-Smart Metering; Non-Technical Losses; Smart Grids; Power Theft

I. Introduction

India is the world's 6th largest energy consumer, accounting for 3.4% of global energy consumption by more than 17% of global population [1]. Due to the fast-paced growth of India's economy, the country's energy demand has grown an average of 3.6% per annum over the past 30 years [2]. Hence India is a major player in the area of power generation and distribution.

It is reported that, in India, out of the total energy generated, only 55% is billed and only 41% is realized [3]. Most of India's state run electricity companies are close to bankruptcy, collectively losing $4.5bn a year, about 1.5% of India's GDP [4]. Power cuts due to load shedding are a regular event in Indian cities, and Bangalore is no exception.

One of the principal reasons for this scenario is the presence of non-technical energy losses (NTL), i.e., losses that are caused due to theft of energy, meter malfunctions etc. The percentage of total T&D losses reported is 30% as per the Ministry of Power, though this figure is optimistically low. Hence it is quintessential to curb the NTL for an efficient future of energy distribution in India.

The current paper is divided as follows: Section II goes on to describe the status quo of the Indian power sector, and explains why it needs change. Section III analyzes some of the methods proposed to detect NTL, discusses their merits and demerits, and explains why the current method is more feasible in the Indian scenario as compared to the said methods. Section IV discusses how smart grids, if implemented properly, could play a major role to help curb losses in an Indian scenario. Section V describes the solution proposed and how it could be technically realized. Section VI discusses the feasibility of the proposed solution in the Indian power sector. Sections VII, VIII and IX discuss the possible bottlenecks, future optimizations and conclusion.

II. Status Quo

Currently, theft of electricity in India is being done by various ways, like meter tampering, bypassing the meters, or unlicensed and illegal connections through tapping of overhead transmission lines. When there is suspicious activity, the revenue protection team of the Government manually checks the meters in a location to detect a theft. Given the size of the Indian subcontinent and the extent of the electricity theft, this method is not only inefficient but also highly expensive to curb losses.

Given the current conventional grid systems, it is very difficult to locate the power theft because it is difficult to monitor power consumption locally at transformers and relays. There is no feedback system for monitoring power consumption other than domestic metering, which is highly tampered with, in most cases of theft. Also, in most of the places, corrupt officials give a blind eye, which further makes it difficult to identify the actual culprit.

In the largest extent, electricity theft is a problem related to residential customers [5]. Losses for the utilities mean losses for the customers, and this affects the normal process of incentive regulation of the utilities as well. Hence a thorough understanding of the user and owner needs reveals that there definitely is a requirement for a new solution.

All the steps taken so far, to ameliorate the power theft scenario did not yield satisfactory results, and hence a change in the status quo is required.

III. Analysis of Relevant Works

Finding methods for revenue protection of utilities and curbing NTL has been an open research problem for the past decade, and various theoretical ideas towards the same have been proposed [6-12]. Also, the idea of using smart metering and smart grids in India was considered a far-fetched idea till very recent times, but this mindset is rapidly changing due to evolving technology, and new methodologies involving smart grids and smart metering schemes are being proposed [13-18].

But these methods have not been successful in curbing NTL at a commercial level due to various factors such as inherent mathematical limitations, practical feasibility, commercial availability, lack of centralized control and infrastructure etc.

For example, [6] discusses a relevant mathematical approach to detect energy thefts, but it is limited in the sense that it truncates quantities lower than 1kWH, and faces some difficulties in evaluating accurately frauds that are external to the meter, that are usually done through bypasses. Obviously, this method, if implemented, fails at some point in an Indian scenario, where majority of the fraud is committed through meter bypassing. Also, the use of a central observer meter as opposed to peer-to-peer communication might pose the risk of a single point failure. That is, if the central observer meter goes down, the system goes down.

Another method for detecting NTL is presented in [11], but it involves an 'Inspection Process', which again is not a cost effective methodology in a country as vast as India.

Commercially, in India, Grinpal Energy Management has begun deploying smart meters and advanced metering infrastructure in New Delhi, for Tata Power [19]. Their solution involves the usage of a prepaid metering scheme, the feasibility of which is debatable in an Indian scenario. As stated in [18], the reliability of prepaid meters is lower than the induction meters. Methodologies dealing with prepaid meters such as the ones presented in [16] and [19] are not viable in India due to a multitude of social and economic factors.

Some solutions such as [20] have gone so far as proposing to restructure the Indian Power Sector, but the practical or commercial feasibility of such solutions is very low, as they mainly involve policy decisions by the Ministry of Power, India.

The solution proposed in this paper aims to overcome most, if not all, of the above cited limitations of the methods that are already in place in India, and aims at giving a commercially viable approach to curb the NTL in India.

IV. Role of Smart Grids in India

In India, T&D losses have been as high as 32.86% for the year 2000-2001, and have been on the rise ever since. The reduction of these losses is essential for the efficient revenue protection of the state run utilities. In India, high technical losses are due to factors such as unplanned extensions of the distribution lines, overloading of transformers and conductors, and lack of adequate reactive power support. As discussed earlier, non-technical losses are due to the meter tampering, meter bypassing, attaining illegal connections, and other forms of energy theft.

Identifying each of these factors individually by the usage of vigilance/inspection teams and taking measures to control the losses, is highly costly, infeasible and inefficient in a vast country like India. Hence, there is a need for mechanisms like smart grid that could provide a two-way communication between the supplier and the consumer. Smart grid includes methods for automated monitoring systems, to keep track of all the energy that is flowing in the grid. It also includes mechanisms for efficient energy distribution, digital two-way communication, self-healing, automated billing and energy theft detection; mechanisms that the conventional grid system lacks.

In a vast country like India where detection of losses by conventional methods is cumbersome, once the smart grid infrastructure is in place, the expenditure involved in the domain of revenue protection would drastically come down, and revenue protection would be an easier task to realize. Also, since smart grids could be implemented as retrofit solutions to the conventional power grid, the feasibility of the idea is very high, and some measures to implement smart grids in India are already in progress.

V. Proposed Solution

The solution proposed is two fold. The first phase involves setting up the necessary infrastructure by introducing smart components into the conventional grid. The proposed idea is to utilize Smart Metering at domestic level as well as at every relay and transformers. All these Smart Meters shall be mutually communicating on a 'data through power lines' communication network or wireless network, and continuously conducting an energy balance survey between the transformers and domestic power consumption.

The second phase of the proposal includes development of such communication protocols where all the smart meters are on a peer-to-peer network communication with each other as well as back to the transformer. In case of the event of energy theft, the software algorithms detect the anomalous behavior in a particular grid or channel and locate the theft. An alarm will then be dispatched via SMS or email service to the local substation.

A prerequisite for implementing this solution is that the technical losses must be known before implementing this mechanism, failing which, we can only identify the total T&D losses but cannot accurately isolate the NTL. The technical losses can be calculated by methods such as the ones proposed in [27] and [28] after adapting them to suit the infrastructure of India.

The two phases of the proposed solution are realized the following way:

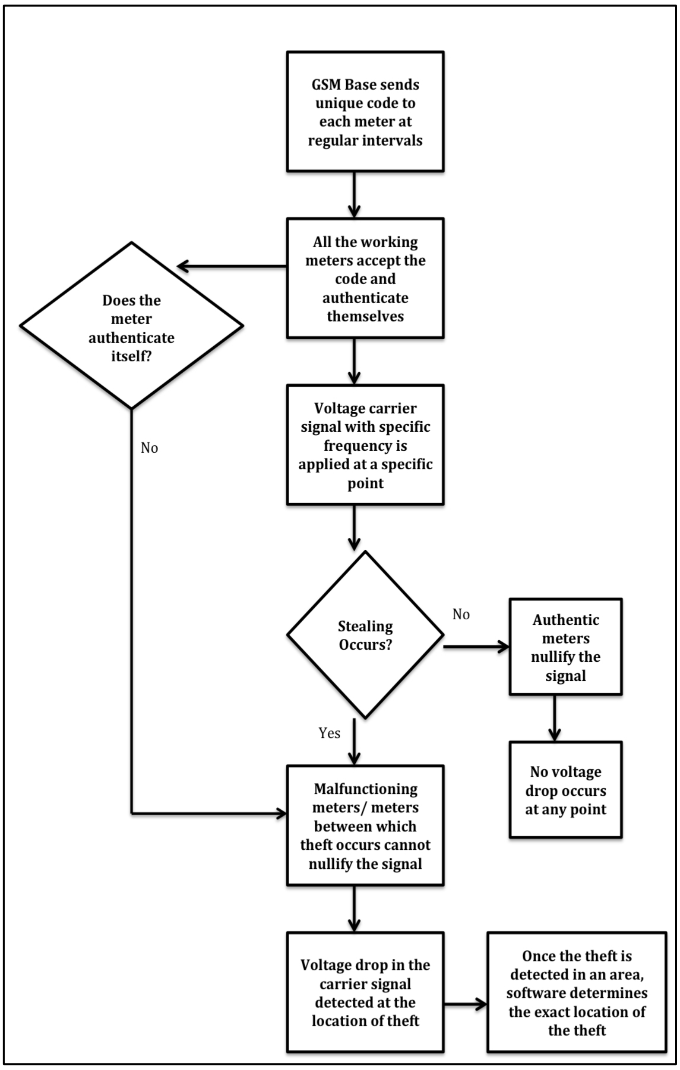

Figure 1. Flowchart of the Proposed Mechanism

- **Functional System:** Installation of smart meters in the **conventional** grid using half duplex communication protocols for detection of theft/losses.
- **Diagnostic System:** Diagnostic measures use software and algorithms to pinpoint the exact location when there are losses detected.

The two systems work in harmony with each other, and the workflow of the mechanism can be illustrated as described in Figure 1.

A. Functional System

This system involves installation of smart meters with an inbuilt SIM card, to communicate with a GSM base. As shown in Figure 2, there is a transformer Tx, which supplies electricity of 230v, to N houses with smart meters coupled to the grid.

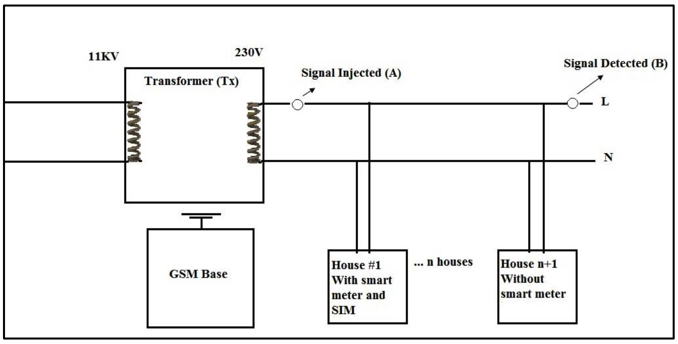

Figure 2. Architecture of the Proposed Mechanism

The smart meter and GSM base use half duplex communication and work the following way:

- Initially GSM base sends a signal to all N houses with smart meter, which will be a unique code for a specific period of time, say 6 hours. The code would again change after every 6 hours. For example, the code 1001011010 can be sent at the t^{th} hour, and it can be updated with the code 1001010011 at the $(t+6)^{th}$ hour.
- All the N meters accept this signal, and the meters are updated.
- Once all the meters respond, a low voltage carrier signal is injected at point A.
- For the signal injection at point A, IEEE p1675 [25] can be used. Currently it is being used for BPL (Broadband over Power Line) signal injection.
- This signal travels through grid. The smart meters with the new code nullify the signal, thereby authenticating themselves.

In the case of energy theft, or meter malfunctioning,

- Suppose N+1 house is stealing electricity from grid, the code will not be updated by house N+1. The carrier signal will appear at the neutral line, which is detected at point B, as illustrated in Figure 3.
- This detection will reveal the area of theft, but it is limited in the sense that it cannot pinpoint the exact location of the theft.

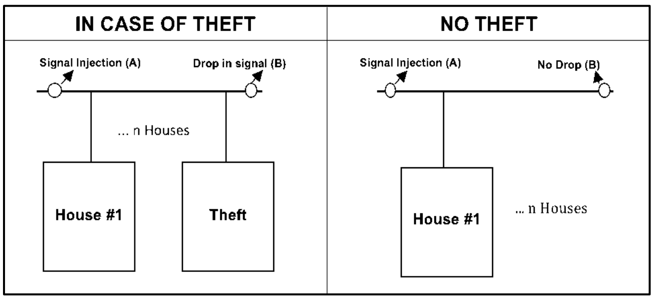

Figure 3. Illustration of the Case of Energy Theft

The exact location of the theft can be further narrowed down using the diagnostic system, which involves software and algorithms specifically designed to realize the same.

B. Diagnostic System

This phase of the solution involves using software and algorithms to pinpoint the exact location of theft, and also to monitor the energy usage and technical losses incurred. It depends on a peer-to-peer network communication between the smart meters. As soon as theft is detected in a location, the software helps to narrow down the exact place of the theft.

The algorithm used in this phase can be emulated using BOUNCE [26]. It is a tool that is used to animate the shock wave or changes in the transmission line. Methods such as the ones proposed in [24] can also be used, after adapting them to the current model and tweaking them in the necessary way.

The system essentially works the following way:

Suppose there is a theft between houses of meter number 2 and 3. Then, when the circulation of algorithm starts from meter 1, meter 1 being legal confirms. It would then transmit the algorithm to meter 2. Since meter 2 is legal it also transmits. But since there is theft between meter 2 and 3, the signal is not received at meter 3.

This type of diagnostic helps in pinpointing the exact location of theft, without any labor, and hence is useful in a scenario like the Indian power sector, where a lot of revenue is spent on manual detection of energy theft/losses.

VI. Feasibility

With the recent advancements in technology, the Indian power sector is also undergoing various changes such as the inclusion of smart components into the conventional grid, the rise of private utilities as opposed to state run utilities etc. In a scenario like this, the utilities are constantly looking for new ways to detect and optimize the T&D losses, and having a cost effective mechanism to identify these losses would mean giant returns commercially.

The proposed solution is targeted mainly towards the Indian consumer, and acts as a retrofit to the infrastructure already in place in India. Hence the commercial feasibility is high, as it does not involve unforeseen expenditure to develop the infrastructure other than the cost involved for the setup of smart meters. The solution could be implemented through minor tweaking of the existing protocols, and hence the technical feasibility is also satisfactory.

From a socioeconomic perspective, the feasibility of the current solution in remote and rural areas of India is debatable, as some of the rural areas lack the basic infrastructure of power supply. Hence it could be said that at this stage, the current solution is more feasible for urban areas as compared to rural areas.

VII. Bottlenecks

Commercially, the initial cost of investment could be a hurdle towards investing in the proposed solution, but its long-term returns in reducing the cost of determining energy losses in a country of India's size, far outweigh the initial investment. Once the infrastructure is in place, the cost involved would be the cost of deployment of the software mechanisms, which is negligible.

From a technical perspective, the security, privacy aspects, and software evaluation of smart meters is still an area to be explored, and various concerns have been raised regarding information theft, privacy breaches, ease of hacking of the smart meters etc. Works such as [21] have discussed the legal metrology perspective of the same, and [22] provides a mechanism to ensure privacy.

VIII. Scope for Future Optimizations

The solution proposed currently is to principally detect T&D losses, but the software and algorithms can be tweaked at a later stage to include mechanisms like dynamic billing such as the one proposed in [23].

The current solution proposes to use protocols like IEEE p1675 and open source technologies like BOUNCE, but these protocols could be substituted for better methods, if any, based on further research.

IX. Conclusion

Statistics show that energy losses in the Indian power sector are significant enough to threaten the closure of utilities. The conventional solutions currently under deployment in India are not cost effective, and the upcoming solutions need to be customized to suit the Indian scenario.

This paper analyzes the current methodologies already in place in India, discusses the efficacy of those methodologies, and provides a novel mechanism to identify the energy losses, with an approach that is a retrofit to the infrastructure already in place in India.

The proposed approach aims at solving some of the major problems faced by the Indian power sector like manual inspection, power theft, meter tampering, manual billing etc. It is cost effective enough to be deployed in rural areas in the future, provided they are equipped with the basic power supply infrastructure.

With this solution in the pipeline, utilities can gain major savings in the domain of revenue protection.

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