2021 6th International Electrical Engineering Conference (IEEC 2021)
April, 2021 at NEDUET, Karachi, Pakistan

Strategy to Detect, Quantify and Locate Power Theft in a Distribution Network

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Abstract: To analyze a distribution Company performance, power loss is a crucial factor. Distribution companies encounter Transmission and Distribution losses, which consist of technical losses and Non-technical losses (NTLs). NTLs are a big issue for power systems in a developing country like Pakistan, and detection of these losses has been difficult for distribution companies. Power theft is one of the main reasons behind NTLs. This paper proposes a novel strategy to identify and locate power theft in a distribution network. Results of simulating the strategy on data of a real distribution feeder in Lahore demonstrate its effectiveness in detecting, quantifying and locating power theft in real-time.

Keywords: Non-technical loss, Power theft, advanced metering infrastructures (AMI)

I. INTRODUCTION

Electrical losses are a challenge for utility companies in the power system of a country. These losses occur along the whole value chain from the generation of electrical power to the consumer level where the power is consumed. Fig 1 shows the exhibit of losses in electricity flow [1]. Most electrical losses are present in the transmission and distribution (T&D) phase. Transmission losses are mostly technical, whereas Distribution losses consist of both, technical and non-technical. Technical losses are inevitable wastage of power in the electric components used to transmit and distribute the power to the consumer end, and these can be calculated easily. NTLs have been the main problem for distribution companies as they are hard to detect. The most significant drawback of NTLs is that the burden of NTLs would be covered by consumers paying bills. There are multiple aspects of NTLs in which power theft is the main one.

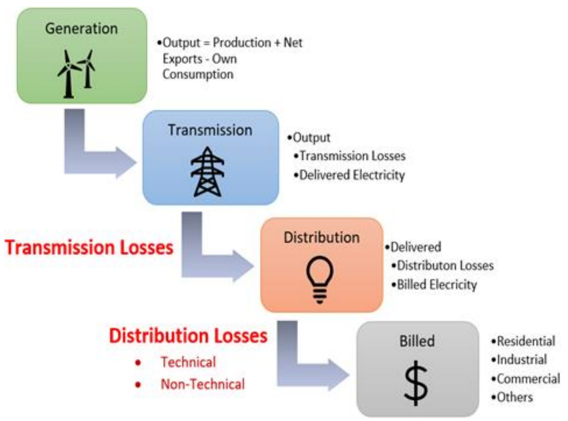

Fig. 1 Power losses in electricity flow

It has not been easy for the distribution companies to find people liable for theft [2]. NTLs affect the quality of electrical energy as supplied voltages to customers are changed due to an increase in load. NTLs also increase the load on the power generating station. NTLs create difficulties in the distribution of power and have a substantial blow on the country's economy. Although NTLs exist around the world, the most damaging consequences of NTLs are found in countries with developing economies. In Pakistan, distribution companies are not very efficient as they lost more than Rs 45 billion in 2017-18. The average of Transmission and distribution losses of DISCOs is 20.7% [3]. Pakistan has seen a rise in T&D losses in recent history. Data from the world bank show a trend of increase in percentage losses, as shown in Fig 2.

Power theft is a complex issue with many causes and effects. Parameters that cause power theft include the issues like infrastructural, economical, and managerial mismanagement. Power theft is a regional, social, and political problem in most developing countries. A reason for billing anomalies is corruption by employees of power companies to cover illegal use. Corrupt employees may intentionally register lower metered value than actual power consumed.

It is need of the hour to identify and find power theft in the distribution system for utility companies. To properly predict and reduce power theft, the electricity distribution system still needs reform. In assessment of the issue, it would be highly desirable to come up with a solution that can detect the presence of theft so that the illegal customers are punished. Locating the area with power theft will be the first step along the way.

II. POWER LOSSES

The electric power losses in the system affect power flow towards users, and it can be divided into technical and non-technical losses of various types, as illustrated in Fig 3. The difference between energy supplied and energy billed is defined as power losses [4].

$$P_{\text{LOSSES}} = P_{\text{SUPPLIED}} - P_{\text{BILLED}} \quad (1)$$

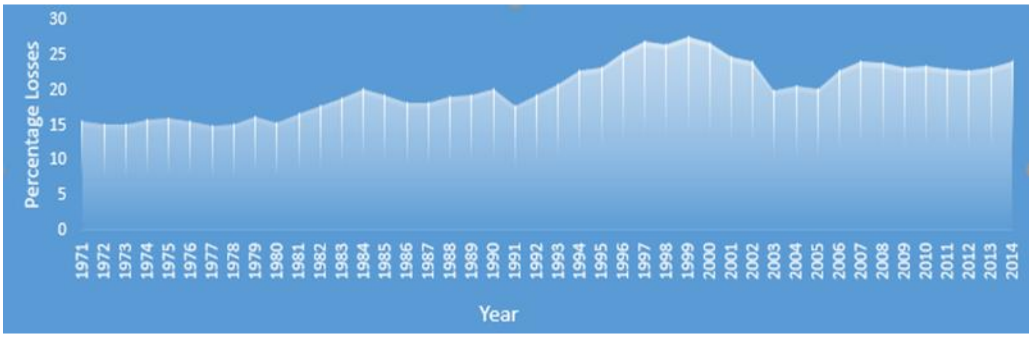

Fig. 2 Transmission and distribution losses of power system of Pakistan [5]

A. Technical losses

These are the primary power dissipation in terms of electrical system elements. Technical losses are naturally occurring losses. These losses result from the unavoidable consumption of electric power into the equipment required for the implantation of transmission and distribution systems. These losses occur in dielectrics and conductors by Joule's effect for transmission and distribution [6]. These losses can be further classified into the following types.

1) Fixed technical losses: These losses are due to the physical inefficiencies of the power system elements like hysteresis losses or eddy current losses in power transformers.

2) Variable technical losses: These losses vary based on the value of the current flow in the transmission lines or transformers.

B. Non-technical Losses

These losses are present due to sources unknown to the power system. These losses are the difference between total T&D losses and technical losses. Estimating non-technical losses is problematic as these are the losses that occur due to anonymous illegal energy flows. There are four significant aspects of NTLs including theft, fraud, unmetered supply, and mismanagement [1].

1) Theft: It refers to the energy that is illegally abstracted from the system, mostly by direct connection. Theft is the major contributor of NTLs that has the most devastating effect on the power system network. Utilities and industry have seen increasingly interested, in the detection of power theft.

2) Fraud: It represents the customers who modify the energy measuring device (meters) to register low consumption than actual. [7]

3) Unmetered supply: It is the consumption of energy for public usages like streetlights and traffic lights. If the usage of these unmetered supplies is known by utility companies, these losses can be modeled with power system network and considered in technical losses.

4) Mismanagement refers to the errors of the accounting and record department of the utility company.[8]

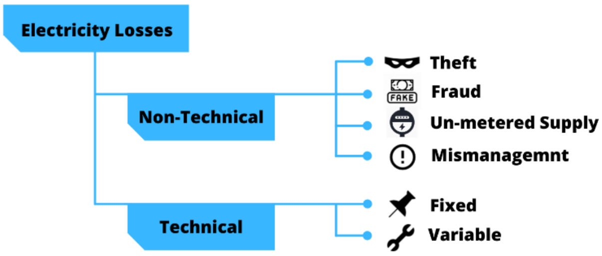

Fig. 3 Classification of power losses

III. THEFT DETECTION TECHNIQUES

Power Theft has been the main reason for NTLs in a distribution system since the beginning. Efforts have been made to detect the people who are responsible for the theft. Various techniques are being used to detect power theft which can be classified into the following types [9].

A. Classification based techniques

These schemes are based on smart meter data collected from AMI and stored over a prolonged period. They predict the NTLs to classify consumption endpoint as theft area or non-theft area. Most of these techniques use machine learning algorithms like Support Vector Machines (SVM), Fuzzy Classification [10], and Neural networks. The main shortcoming of these methods is the availability of the customer's historical data to train the algorithms.

B. State-based detection

These techniques rely on monitoring the state of the distribution system to improve the detection rate. Monitoring devices are installed and implemented in these techniques. Some examples of these techniques are sensor monitoring [11], mutual inspection, and physical monitoring. The main disadvantage of these schemes is the investment needed for monitoring devices. After the installation, operation cost, training cost, and software cost are also required for the devices.

C. Estimation based techniques

These techniques use the estimation of NTLs from a zone or consumer location to identify power theft. The state estimation focuses on searching for theft by using the available measured values, normal load, and current measurements of energy flow at distribution system nodes. Modeling of technical losses is used to estimate the NTLs [12].

D. Game theory-based

Game theory-based detection systems provide fresh insight for solving energy theft. The problem of identifying energy theft is conceived as a contest between the energy supplier and the thief of power [13]. However, determining the utility function and possible strategies of all parties is still a difficult challenge.

IV. PROPOSED STRATEGY

This paper proposed a cost-efficient as well as easy to implement strategy to identify and locate power theft. This strategy is based on estimation-based techniques where we use the modeling of technical losses to determine the area having large NTLs. As transmission losses only consist of technical losses and these losses are also very low due to the high voltages, transmission losses are out of this study's scope. Fig 4 shows losses of distribution company "LESCO" for the year 2017-18. The losses in power and distribution transformers are not being considered because these are constant technical losses. The scope of this work is for power theft detection, localization, and quantification between power transformers and distribution transformers. The main aim of this study is to enable a DISCO in determining the percentage of power theft among its total T&D losses.

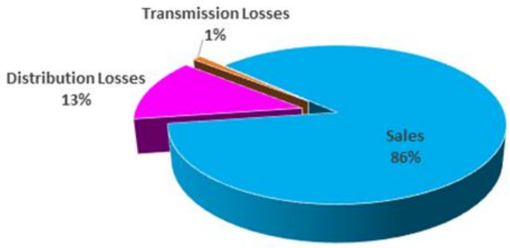

Fig. 4 Percentage Energy Sale and Losses (Transmission and Distribution) of LESCO for 2017-18 [14]

A. Identify Non-Technical Losses

The data from a DISCO is collected, and a distribution network model is designed and developed based on this data. Metered loads are gathered from smart meters on utility transformers using AMI. After this, load flow analysis is used to determine the technical losses of the developed system. The first task is to identify whether potential NTLs are present in the system or not. All the elements of this distribution network like transformers, lines are designed and implemented in OpenDss. The reason to choose OpenDss is that it is a lightweight application that can easily handle unbalanced loads. Technical losses are calculated using the power flow method. The simulation results give the power required to deliver the metered power and cover the technical losses. By comparing this to the actual energy supplied from the grid, any NTLs present in the system can be identified.

B. Quantifying Power Theft

Once it is established that the system has non-technical losses, the next task is to quantify them. Power theft is a major part of the non-technical losses, and this research work does not model other types of non-technical losses. It is pertinent to note that power theft is a non-technical loss that also increases technical losses due to increased power flow.

$$\text{Total Energy Loss} = P_{\text{SUPPLIED}} - P_{\text{BILLED}} \quad (1)$$

$$\text{Total Energy Loss} = \text{NTLs} + \text{TL} \quad (2)$$

comparing both equations result in

$$\text{NTLs} = P_{\text{SUPPLIED}} - P_{\text{BILLED}} - \text{TL} \quad (3)$$

C. Localization of Power Theft

As we have concluded that there is power theft in the system, localization would be beneficial as it would help to eliminate the theft. For this purpose, actual voltages of the secondary side of distribution transformers are collected from AMI. From the simulated system, voltages of the transformers are also calculated. The difference is measured by comparing both actual voltages and measured voltages. If this difference in values at any point is bigger than average difference, power is being stolen at that point. Fig 5 presents the overall flow chart of the proposed strategy.

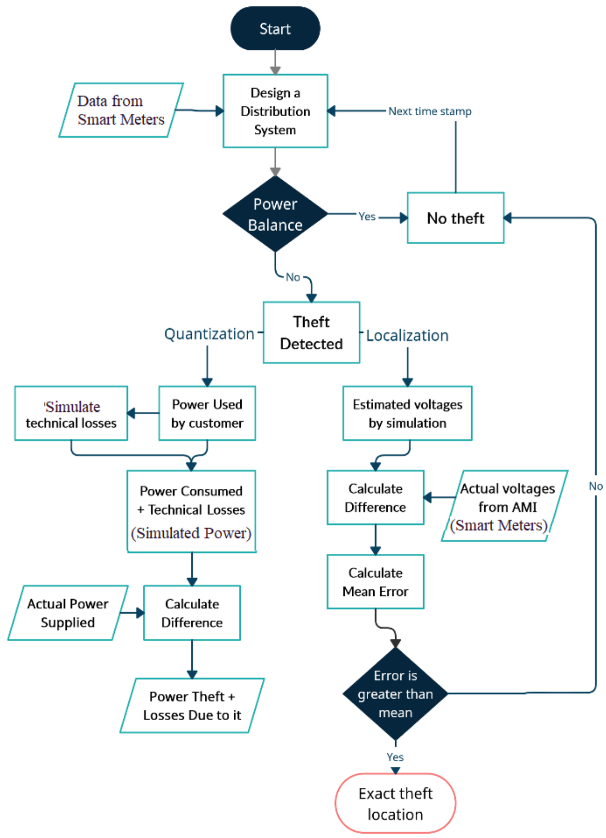

Fig. 5 Flow chart for the proposed strategy

V. COMPARISON WITH OTHER METHODS

Power theft has emerged as a major problem for power systems and efforts have been made to develop strategies so that this loss can be eradicated. Previously used techniques are mostly based on machine learning algorithms. These algorithms need historical data of customer usage of electricity to detect abnormal power supply as Power theft. This can be done by installing necessary equipment and monitoring the usage for some time. Other techniques use inspection of the equipment installed manually or by mutual parties.

Our proposed technique does not require the history of power consumption of user. It will find power theft in real time as the supplier will get the power consumption information from Smart meters which are installed at user end. In this way, the supplier will know how much energy is required to fulfill the consumer demand and to compensate the technical loss at that specific time. If actual power supply is bigger than the needed power, there might be some power theft present in the system.

VI. Implementation of the Strategy

To study the proposed strategy, data of a distribution feeder named "Gulshan-e-Iqbal" is collected from LESCO. This feeder system is then designed in OpenDss. For research purposes, it is considered that the loads are being collected from smart meters on transformers using the AMI system.

A. Software implementation

Actual loads based on AMI from the secondary side of the utility transformers of the feeder system are fed to the system designed in OpenDss. These loads are added in simulation as lumped to the secondary side of the transformers. OpenDss can easily calculate the losses present in utility transformers and add them into technical losses. The load flow method is applied to this system so that we get the value of the required power to deliver the customer loads and compensate for the technical losses. Fig 6 shows the simulation of power flowing through the feeder system. Red triangles are used to mark the transformers for reference. Transformers on which power theft is suspected are labeled in red.

B. NTLs Quantification

This method is based on the analysis of the power consumed. The difference between simulated and actual results is analyzed. NTLs are calculated by the abstraction of simulated or estimated power from actual power. These NTLs are power theft and technical losses due to it.

C. Voltage Analysis

The voltages of the transformers from the simulation file are exported to a spreadsheet using OpenDSS export command. These voltages represent calculated voltages at every transformer due to the metered loads. Analysis can be done on this data in MS Excel. To get the value including theft for research purposes, some extra loads referred to as theft are added to the simulation file and export the voltages values. These voltages represent actual voltages from real life. Analysis of actual voltages and simulated voltages shows that power theft affects all the nodes in the system and even the voltages of the nodes which are free of power theft are also changed. The difference between measured and calculated voltages is calculated to study the error.

VII. Results

The simulation for metered loads is done to see the required power which should be delivered by the grid to supply power to customers. The results are as under:

Simulated Power = Total metered power + Technical losses = 5.68835 + j3.41867 MVA (4)

The technical losses according to simulation are 0.305275 + j 0.305275 MVA which are 6.5 % of the total power supplied. These losses are much less than the actual losses of utility company LESCO which are 13% as shown in Fig 4. The difference between the simulated technical losses in this feeder and actual distribution losses of LESCO is 6.5%. This shows that our methodology can discover power theft in distribution systems. Furthermore, assuming that it is a typical feeder, power theft magnitude in LESCO is as much as its technical losses. Note that these 6.5% of the NTLs in the LESCO distribution system cover the power theft and the additional copper losses due to this power theft.

Although effectiveness of strategy is demonstrated by using data of one real feeder in LESCO, scalable and generic nature of the strategy empowers it to work for whole distribution network of LESCO, if the network data becomes available for research.

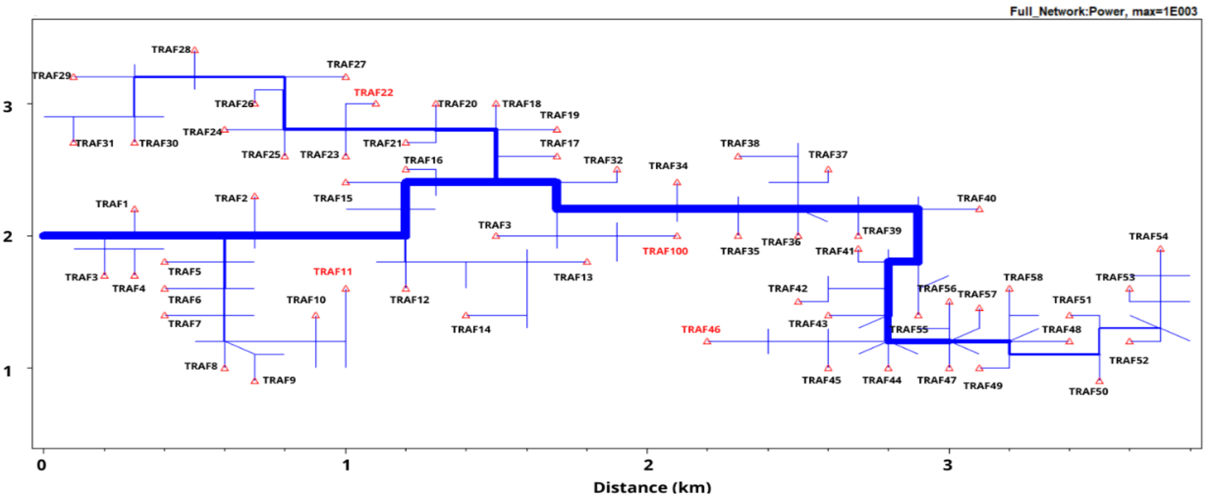

Fig 6 Power flow simulation of Gulshan-e-Iqbal feeder

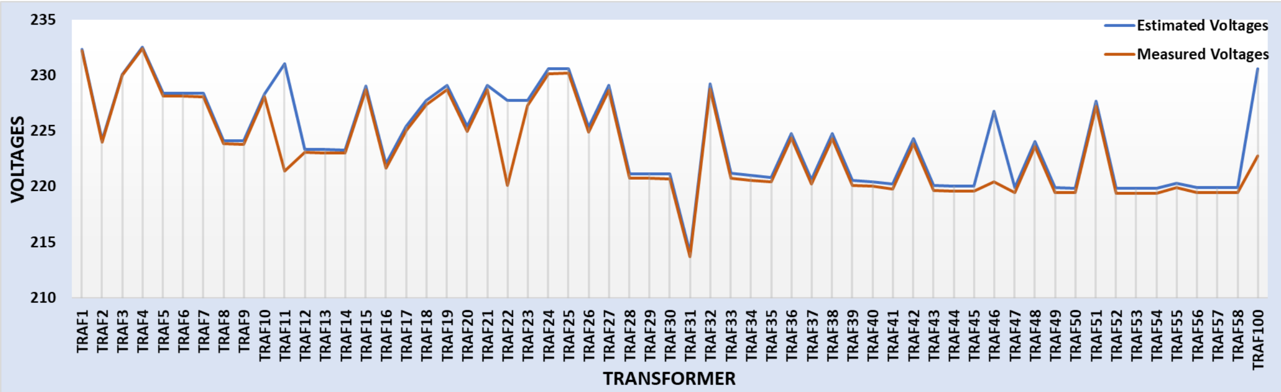

Fig 7 Voltage levels of distribution feeder

A. Case I

There are fifty-nine transformers in the system and power theft of 0.44 + j0.20 MVA is added in four of them to see the results. Four transformers on which theft is added are TRAF11, TRAF22, TRAF46, and TRAF100. The simulation is run which gives the total power supplied represented as actual power supplied.

Actual Power Supplied = 6.11486 + j3.62847 MVA
Power Theft + Losses due to it = Actual Power Supplied – Simulated Power (5)
Power Theft + Losses due to it = 0.42636 - j0.2098 MVA

Fig 7 represents the graph of estimated voltages vs actual measured voltages. The actual voltages of the four transformers are much less than the estimated voltages. The error at every transformer is calculated for the analysis of the difference between measured and estimated voltages. The mean absolute error (MAE) of this system is calculated, which turns out to be 0.885. After comparing the errors with MAE, four transformers are identified whose errors are greater than MAE. These are the transformers where non-metered loads were added as power theft. Table 1 shows the results.

Table 1 Located Transformers with Power Theft

Transformer	*Power theft (kVA)*	*Estimated voltages*	*Measured voltages*	*Absolute Error*
TRAF11	140 + j80	231.0	221.4	9.6
TRAF22	100 + j40	227.7	220.1	7.6
TRAF46	100 + j40	226.8	220.4	6.3
TRAF100	100 + j40	230.6	222.8	7.8

B. Case 2

Theft is added in 25 percent of the total transformers i.e., 15 transformers to see the effect. Fig 8 illustrates the voltage profile estimated by simulation of only metered loads. The voltage profile in Fig 9 shows actual voltages at the user end of the transformers when power theft is added to the system. Comparing both graphs shows that the voltages within the system are shockingly low due to power theft. Simulation results are as under:

Actual Power Supplied = 6.68014 + j4.75867 MVA
Hence, power theft and technical losses due to it are 0.99179 + j1.34 MVA.

This value is close to the amount added as power theft which is1.11 + 1.38 MVA. This demonstrates successful quantification of power theft.

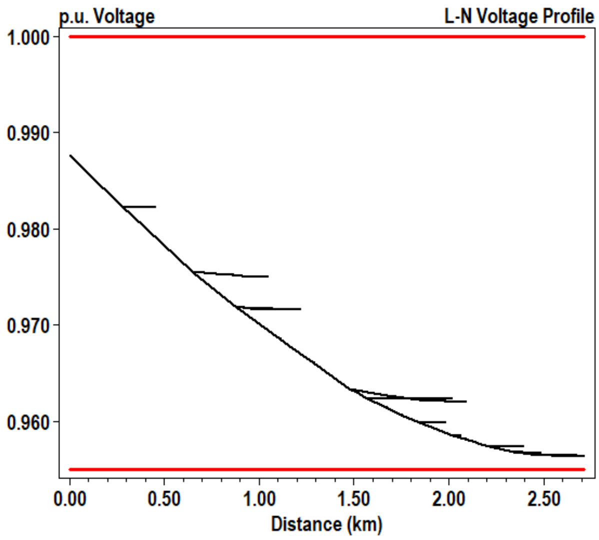

Fig 8 Voltage profile of the Distribution feeder with metered loads only

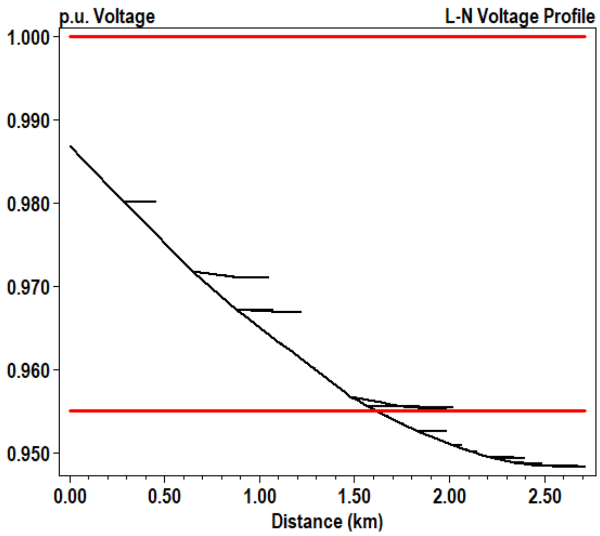

Fig 9 Voltage profile of the Distribution feeder including power theft

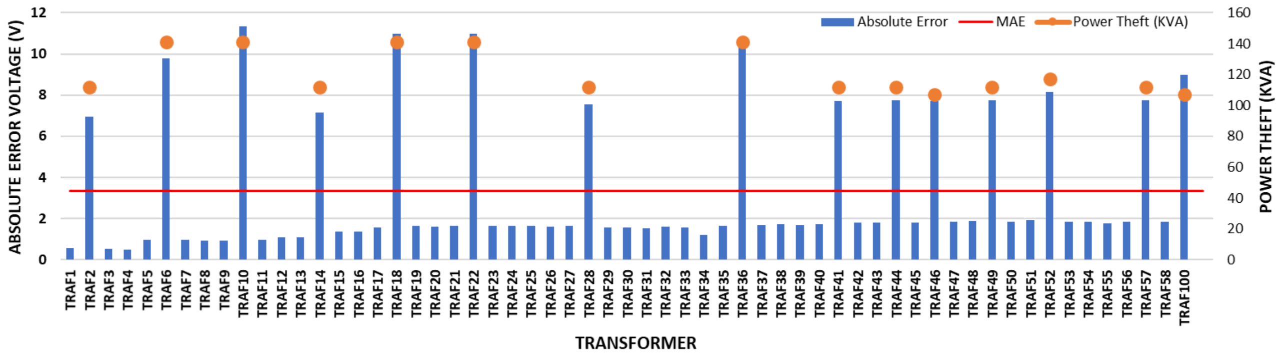

Fig 10 Absolute Voltage Error vs Power Theft in Distribution feeder

Fig 10 illustrates the absolute error between the values of estimated and measured voltages at each transformer. Mean Absolute Error (MAE) is also plotted as a red line and the graph has exactly fifteen peaks of absolute voltage error above the MAE at corresponding transformers where non-metered loads were added as power theft. This demonstrates successful localization of the area with power theft. Fig 10 also plots the power theft at each transformer. It can be noted that the absolute voltage error is not the same at every power theft location. As seen, the error at TRAF2 is lower than TRAF6 because the amount of power theft is less at TRAF2.

Comparison of TRAF6 and TRAF10 shows that the error at the former transformer is less even though the amount of power theft is the same on both transformers. The reason for this result is that despite being in the same lateral branch, TRAF6 is closer to the main branch than TRAF10. Hence, it can be concluded that voltage error depends on the amount as well as the position of the power theft in the system.

VIII. PRACTICAL IMPLEMENTATION

This strategy can be implemented in practical world to identify power theft in real time. Smart meters and AMI are needed to be installed in our distribution networks so that the real time information of power consumption values like currents and voltages are collected. These currents are gathered in a base center where it is used to simulate the designed network and calculate the voltages. By comparing the simulated voltages with the actual voltages coming from smart meters, we can locate the consumers with power theft.

In developing countries like Pakistan where implementing smart meters to every household is a difficult process, this strategy can be implemented on a bigger scale. For example, smart meters can be installed on every utility transformer. Once the transformer containing power abnormalities is identified, the area under that transformer is marked as power theft location. Similar approach is adopted in this paper where analysis is done on transformers of the distribution system of LESCO.

IX. CONCLUSION

The transition toward the smart future of the power grid demands to enhance the distribution networks by increasing their reliability and flexibility. This aim can be achieved by reducing the losses of the power system. Most of the power losses in Pakistan are due to the actions external to the power system. Power theft is the most prominent contributor to non-technical losses. This research work provides a strategy to find, quantify, and locate the power theft in a distribution network.

The illegal extraction of power is becoming a usual practice in Pakistan. This exercise increases the load on the generation and harms the whole power system. Power theft also yields a substantial economic loss for the country. The strategy proposed in this paper will help to locate the culprits so that the illegal users are held accountable.

REFERENCES

[1] R. Jimenez, T. Serebrisky, and J. Mercado, “Sizing Electricity Losses in LAC Transmission and Distribution Systems,” 2014. (https://publications.iadb.org/publications/)

[2] S. Shekara, S. Reddy, L. Wang, and V. Devabhaktuni, “Electricity theft : Overview , issues , prevention and a smart meter based approach to control theft,” *Energy Policy*, vol. 39, no. 2, pp. 1007–1015, 2011.

[3] Nepra Performance Evaluation Report of Distribution Companies for the year 2017-2018. (https://nepra.org.pk/Standards/2019/PER DISCOs 2017-18 (Final).pdf)

[4] T. Ahmad, “Non-technical loss analysis and prevention using smart meters,” Renew. Sustain. Energy Rev., vol. 72, no. November 2015, pp. 573–589, 2017.

[5] World Bank Data. Annual Energy Outlook 2014. ⟨http://data.worldbank.org/ indicator/EG.IMP.CONS.ZS⟩.

[6] J. L. Viegas, P. R. Esteves, R. Melício, V. M. F. Mendes, and S. M. Vieira, “Solutions for detection of non-technical losses in the electricity grid: A review,” *Renew. Sustain. Energy Rev.*, vol. 80, no. June, pp. 1256–1268, 2017.

[7] M. Zanetti, E. Jamhour, M. Pellenz, M. Penna, V. Zambenedetti and I. Chueiri, "A Tunable Fraud Detection System for Advanced Metering Infrastructure Using Short-Lived Patterns," in *IEEE Transactions on Smart Grid*, vol. 10, no. 1, pp. 830-840, Jan. 2019.

[8] Aggarwal, A., Beniwal, R.K., Kumar, R. and Kumar, "Non-Technical losses in power distribution" in system. *International Journal of Engineering, Science and Mathematics*, vol. *7*, no. 2, pp.329-338, 2018.

[9] R. Jiang, R. Lu, Y. Wang, J. Luo, C. Shen, and X. S. Shen, "Energy-Theft Detection Issues for Advanced Metering Infrastructure in Smart Grid," vol. 19, no. 2, pp. 105–120, 2014.

[10] E. W. S. dos Angelos, O. R. Saavedra, O. A. Cortes, and A. N. de Souza, Detection and identification of abnormalities in customer consumptions in power distribution systems, IEEE Transactions on Power Delivery, vol. 26, no. 4, pp. 2436-2442, 2011.

[11] S. McLaughlin, B. Holbert, S. Zonouz, and R. Berthier, AMIDS: A multi-sensor energy theft detection framework for advanced metering infrastructures, in Proc. IEEE Third International Conference on Smart Grid Communications (SmartGridComm), 2012, pp. 354-359.

[12] S.-C. Huang, Y.-L. Lo, and C.-N. Lu, Non-technical loss detection using state estimation and analysis of variance, IEEE Transactions on Power Systems, vol. 28, no. 3, pp. 2959-2966, 2013.

[13] S. Amin, G. A. Schwartz, and H. Tembine, Incentives and security in electricity distribution networks, in Decision and Game Theory for Security, Springer, 2012, pp. 264- 280.

[14] Electricity Demand Forecast based on Power Market Servey ⟨http://ntdc.gov.pk/ ⟩.