International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 9 (2015) pp. 23573-23581

Deduction of Pilferage of Energy Using PLC Signals

Dj. Taniguevelane
Research Scholar, B. S. Abdur Rahman University,
Vandalur, Chennai, India.
velane23@rediffmail.com

Dr. K. N. Srinivas
Ph. D., Professor, Electrical and Electronics Department,
B. S. Abdur Rahman University, Vandalur, Chennai, India.
knsrinivas@bsauniv.ac.in

Abstract

Energy theft minimization is a major challenge to the Utilities across the globe for its financial healthiness. Theft localization algorithms are some of the tools which will enable them to meet the challenge. Many techniques/algorithms are available for theft localization and each of them requires distinct data such as Historic consumption patterns, Network parameter etc. and the effectiveness of theft localization depends on the accuracy of input data. The network parameter data of the service line of the consumers is one of the data required for some of the Theft localization algorithms. As the length of the service line of consumers is difficult to measure due to the fact that those are laid underground or inside the buildings, a method to estimate the network parameters in such situations is desired. This paper analyses some of the network parameter estimation techniques and its practical limitations for applying to the LT distribution network and proposes an algorithm to estimate the line parameters of service lines based on the smart meter data and using the distance measurement feature of the PLC signals. This paper also analyses the effectiveness of the theft localization using the network data obtained with the proposed algorithm.

Key terms: Non-Technical losses, Smart meters, AMI, PLC.

Introduction

The Electrical power distribution system is the final and crucial link in the electricity supply chain. It assumes great significance as the segment has a direct impact on the sector's commercial viability and ultimately on the consumers who pay for power services. High distribution losses due to theft of electricity affect the financial viability of the distribution companies and hence efficient power delivery system is required to curb the unauthorized extraction of energy from the distribution system. The unauthorized energy is usually accounted in Transmission and Distribution losses. Even-though the unauthorized energy extraction is usually in the range of 1-2%, the loss in terms of money will be very huge considering the quantity of energy distributed [1]. Due to non-availability of proper energy accounting system in some of the Utilities, the loss may even be higher. The amount of unauthorized energy could be controlled with various anti-tampering features of smart meters [2] and nevertheless, the pilferage of energy i.e., illegal tapping or bypassing of meters could not be detected by Smart meters alone.

The illegal tapping or bypassing of meters is difficult to detect as it is not practicable to check the entire consumer wiring from the Distribution Mains to the Meters regularly by the utility personnel [9]. Hence it requires a scientific mechanism to localize such illegal tapping/by-passing of metering circuit. Several works were undertaken for localization of Non-Technical Loss (NTL) Detection which can be broadly classified into Type I and Type II as defined in [3]. Generally, the Type-I techniques require prior knowledge about customer behaviour and the Type-II techniques generally require network data to detect the by-passing of meters. The Type-II techniques not only employ electrical power system data and equations for localizing of Theft but also effective for identifying theft/pilferage occurring due to new loads of consumers.

A procedure of switching of all nodes remotely and sending a low voltage high frequency signal for calculating the impedance of each line that connect to each meter and comparing of this calculated value with the value measured during installation of the system for detecting illegal load is proposed in [4]. In [5], a method of replacing the non-linear set of equations of the load flow problem with voltage and Complex power data by a linear set of equations is presented. The influence constants for each bus due to the Power consumed on the voltage profile is calculated for time series which do not have any Theft and is optimized with least square solution. These constants will be used for localization of theft on the bus when there is deviation of voltage profile with the calculated value. In [6], the voltage profile along the feeder is estimated based on measurements by the smart meters of the current and power factor of each consumer, and a model of the feeder. This estimated voltage profile is compared with the actual measured profile obtained from meters and based on this comparison, the location of illegal abstraction is determined. In [7], a method to detect bad bus demand data by Distribution State Estimation (DSE) by incorporating irregularities due to meter errors and applying ANOVA for evaluating individual meter anomaly is suggested.

The assumption made in the above methods is that the network parameter data provided is accurate. However, in practical situations particularly in distribution environment, it is difficult to estimate the network parameters accurately. Even, if sincere efforts are taken to measure the individual parameters of the network accurately, the same will be prone to errors imposed by measuring instruments. Further, due to the dynamic nature of the distribution system, the parameters will not be constant and parameters errors will result in incorrect prediction. It is therefore desired that there may be some scientific method to dynamically measure the network parameter and process it to get accurate data for effective NTL localization algorithm to perform. Even though many network parameter estimations algorithms exist, the non-availability of sufficient measurements such line flows at the two ends of lines in LT distribution network will affect the estimation process. In this paper, a modification of state estimation problem to incorporate distance measurement data using PLC signals and Energy meter measurements of LT distribution network is presented to estimate the network parameters. The effectiveness of the parameters thus estimated is analysed for localization of theft.

Proposed Method

In [8], it is shown that the Power Line Carrier (PLC) Communication signals can be used to predict the distance of conductors used in power systems by measuring the Time of Arrival (ToA) to an accuracy of 5 to 7 m. Suppose Node A sends a message to Node B at time 0 and Node B receives the message at τ_B and let the Node B sends a reply packet to A after a known time T, the Node A receives the packet at time τ_A= $2\tau_B$ + T. As the time τ_A is related to the distance d, with c, the speed of light, the distance, d can be derived as

$$d = \frac{c(\tau_A - T)}{2}$$

With the distance obtained above and by knowing the type of conductor and its manufacturing data, the R, X and B values can be obtained and can be used for NTL localization algorithms. However, as the length of the service lines of distribution system will be very short, there will be errors introduced up to 5 to 7m and the above error will result in inaccurate results. A new method of obtaining much accurate parameter estimation from the measured PLC distance data using modified state estimation algorithm is proposed in this paper.

The state estimation is traditionally used to evaluate the present state of power system through evaluation of likely V and θ values using weighted least square method with the metered values such as P, Q, I etc., at various node points and with the accurate network parameters. In the above state estimation problem, equations are formed for the measured quantities and partial derivation of the above equations with respect to V & θ are performed along with iterative solution for Taylor series expansion for minimizing the errors so as to obtain the state estimation values. In the new method proposed, equations for the metered values such as P, Q, V, I etc., along with the network parameter obtained from conductor length measured using PLC signal are formed and partial derivation of these values with respect to the impedance is done in the modified state estimation problem and the value of network parameter is obtained as shown below:

$$h1: \quad V_i = I_{ij} \times Z_{ij} + V_j$$

$$h2: \quad V_j = -I_{ij} \times Z_{ij} + V_i$$

$$h3: \quad P_{ij} = \frac{V_i}{Z_{ij}}(V_i - V_j)$$

$$h4: \quad Z_{ij} = \frac{(V_i - V_j)}{I_{ij}}$$

$$h5: \quad I_{ij} = \sqrt{(V_i^2 + V_j^2 - 2V_iV_j)/Z_{ij}}$$

The partial derivatives of the above equation are used to form H matrix and the value of the network parameter is obtained by iterative solution of weighted least square formation:

$$G(x^k).\,\Delta x^{k+1} = H^T(x^k)R^{-1}[z - h(x^k)]$$

where:

$$\Delta x^{k+1} = x^{k+1} - x^k$$

$$H(x) = [\frac{\partial h(x)}{\partial x}]$$

As the conductor of distribution network have R values much higher than the X and B values, the X and B values are assumed as zero as the aim of the study is for finding the network parameter in the distribution network. Accordingly, the above equations are revised and simulations were carried out for different cable lengths and for different accuracy of meters and the results are shown in Table 1. The assumptions made for this method is that the both ends of Voltages are available within the accuracy limits of the metering equipment and the P and I values are available for the end bus which shall normally be the consumer end. Network parameters for each section of the system are estimated with the proposed algorithm using the metered values available during non-theft periods.

Table 1: Expected Accuracy of Line Parameter Data

Actual Values		Range obtained from PLC	R in Ω obtained from modified state estimation			
in m	in Ω		0.2 Accuracy class meters		0.1 Accuracy class meters	
			Calculated value	% error	Calculated value	% error
10	0.0948	0.02844 to 0.16116	0.1885	98.83	0.1414	49.16
20	0.1896	0.1232 to 0.2559	0.377	98.84	0.284	49.79
30	0.2844	0.21804 to 0.35076	0.1949	41.47	0.2414	15.12
40	0.3792	0.2465 to 0.51192	0.4812	26.89	0.4089	7.83

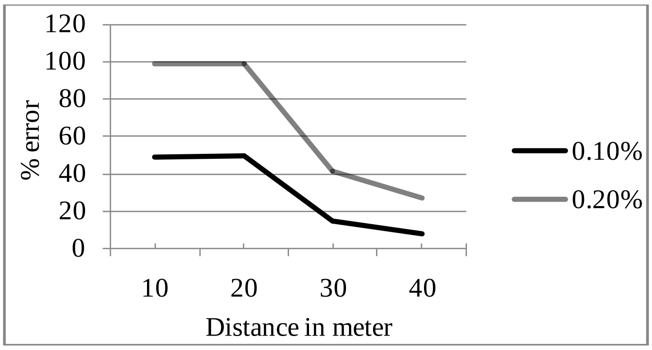

Figure 1: Parameter error vs Length of conductors

From the Table-1 and Fig-1, it can be seen that the accuracy of the proposed method increases with the increase in cable lengths and also with the increase in accuracy of meters. In [10], it is given that some meter manufacturers are claiming accuracy class better than 0.1% accuracy and as such, the parameter error obtained from the proposed method could be minimized with better accuracy meters.

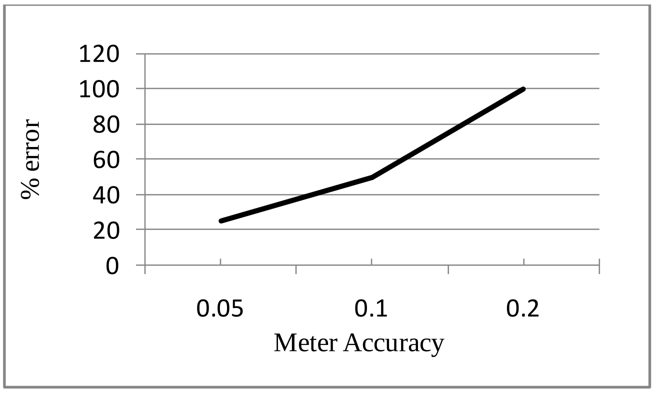

Figure 2: Parameter Error Vs Meter Accuracy For 20 Conductor Length

Testing of Acceptability of Data Obtained From The Proposed Method For Theft Localization

As brought in Section-I, different algorithms exist for theft localization, the localization of theft as brought in [8] is more robust as it identifies the theft at the Bus level i.e., at the particular consumer premises. In order to test the acceptability of data obtained from the proposed method, a similar approach using WLS estimation has been employed. A sample network with a 12 bus LT distribution system as shown in Fig.2 has been considered for the study of viability of localization of NTL with the Network parameter value derived from the proposed method.

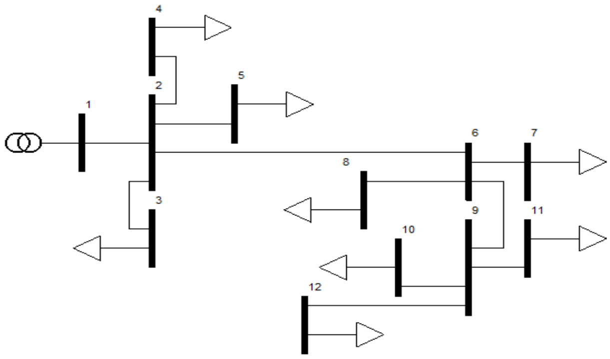

Figure 3: Twelve Bus Test Feeder

The Largest Normalized Residual r_{max}^{N} for identification of a single bad data existing in the measurement set is used to localize the theft/NTL. First, the WLS estimation is solved to obtain the elements of residual vector:

$$r_i = z_i - h_i(\hat{x}), \qquad i = 1, \dots, m$$

Normalized residual, $r = \frac{|r_i|}{\sqrt{\Omega_{ii}}}, i = 1, \dots, m$

Initially, theft/NTL condition is identified by comparing the input energy with output energy. In case of mismatch, the WLS estimation for voltage measurements is performed and normalized residual are obtained for each bus. The bus with the highest values of normalized residuals is suspected for possible Theft bus and is verified. After, elimination of Theft from the bus, in case of further Theft, the procedure is repeated until all the Thefts/NTL's are eliminated.

Table 2: Bad Data Detection by Largest Normalised Residual (r_{max}^{N}) Test With actual network parameter

Bus No	V in pu	Without Theft with actual Network parameter		With Theft at Bus 7 with actual Network parameter	
		V State in pu	Normalized residual error	V State in pu	Normalized residual error
1	1	1	0.0002	1	0.0005
2	No mess	0.9976	NA	0.9976	NA
3	0.9974	0.9974	0.0001	0.9974	0.0002
4	0.9974	0.9974	0.0008	0.9974	0.0005
5	0.9976	0.9976	0.0015	0.9975	0.0018
6	No mess	0.9962	NA	0.9962	NA
7	0.9961	0.9961	0.0006	0.0062	0.0032
8	0.996	0.996	0.0003	0.996	0
9	No mess	0.9951	NA	0.9951	NA
10	0.995	0.995	0.0013	0.995	0.001
11	0.9949	0.9949	0.0012	0.9949	0.0015
12	0.9947	0.9947	0.0003	0.9947	0.0007

Table 3: Bad Data Detection by Largest Normalised Residual (r_{max}^{N}) Test with network parameter calculated with the proposed method considering 0.05 Accuracy Meters

Bus No	V in pu	Without Theft with actual Network parameter		With Theft at Bus 7 with actual Network parameter	
		V State in pu	Normalized residual error	V State in pu	Normalized residual error
1	1	0.9994	0.02	0.9994	0.0203
2	No mess	0.9976	NA	0.9976	NA
3	0.9974	0.9974	0.0001	0.9974	0.0002
4	0.9974	0.9974	0.0009	0.9974	0.0006
5	0.9976	0.9976	0.0016	0.9975	0.0019
6	No mess	0.9963	NA	0.9963	NA
7	0.9961	0.9962	0.0041	0.9963	0.0065
8	0.996	0.9961	0.0029	0.9961	0.0027
9	No mess	0.9953	NA	0.9952	NA
10	0.995	0.9952	0.0055	0.9952	0.0052
11	0.9949	0.995	0.0035	0.995	0.0032
12	0.9947	0.9948	0.0045	0.9948	0.0042

For the twelve bus test system, the Largest normalized residual (r_{max}^{N}) test is conducted for both actual network parameters and for the network parameters obtained from the proposed method. Random errors are introduced on the network parameter values such that the largest error is 25% which can be introduced for a 20 m conductor length with 0.05 accuracy class meters by the PLC distance measurement feature. Table 2 shows the (r_{max}^{N}) test for actual network parameter data and Table 3 shows the (r_{max}^{N}) test for network parameter data obtained from the proposed method. A theft was simulated in Bus 7 and with the network data obtained from proposed method by introducing errors up to 25% randomly; the localization of Theft is identified through identification of largest normalized residual obtained from State Estimation solution.

The proposed method has been tested for IEEE14 bus system by considering the conductor parameters mentioned in [11]. Based on the conductor parameters, the length of the individual feeders is calculated and the error to be encountered in PLC measurements has been introduced. The simulation is performed by considering only the R values of the conductors with measurements of active power flows, Voltage and I values of each branch by introducing meter errors.

Initially, with the no pilferage scenario, the parameters of the conductors are estimated and with the estimated parameter values of conductors and with the simulation of pilferage at bus 12, the proposed algorithm was used to measure the normalized residues. Even with the errors introduced with the measurement of feeder lengths using PLC signals, the results indicate that the maximum residual error could be obtained for the pilferage point at bus 12. The results are shown in Table 4.

Table 4: Bad Data Detection by Largest Normalised Residual (r_{max}^{N}) Test with network parameter calculated with the proposed method considering 0.05 accuracy meters for IEEE-14 Bus System

Bus No.	V input	V without theft	V with theft at bus 12	Residual without theft	Residual with theft at bus 12
1	1.06	1.0638	1.0634	0.00001	0.00001
2	1.0281	1.0306	1.0302	0.00001	0.00000
3	0.991	0.9924	0.9919	0.00000	0.00000
4	1.0028	1.0002	0.9998	0.00001	0.00001
5	1.0107	1.017	1.0166	0.00004	0.00003
6	1.0115	1.017	1.0166	0.00003	0.00003
7	1.003	1.0002	0.9998	0.00001	0.00001
8	1.0023	1.0002	0.9998	0.00000	0.00001
9	1.0026	1.0002	0.9998	0.00001	0.00001
10	1	0.9994	0.999	0.00000	0.00000
11	1.0042	1.0062	1.0058	0.00000	0.00000
12	1.0032	1.007	1.0113	0.00001	0.00007
13	0.9998	1.005	1.0053	0.00003	0.00003
14	0.9901	0.9901	0.9899	0.00000	0.00000

Conclusion

A novel method to overcome the problem of obtaining Network parameter data of a distribution network with minimal error using Time of Arrival measurements of PLC signals is presented in this paper. The applicability of the data obtained from the proposed method is employed for Theft/NTL localization using largest normalized residual test in WLS formulation. The results show that the Theft localization technique employing the network data obtained from the proposed method is comparable to the study made using the actual network parameter data. It is also shown that more accurate network parameter data could be obtained with better accuracy meters.

References

[1] B. Thomas and Smith, “Electricity theft: a comparative analysis,” Energy Policy, vol. 32, no. 18, pp. 2067 – 2076, 2004.S. De, R. Anand, A. Naveen, and S. Moinuddin,

[2] R. Alves, P. Casanova, E. Quirogas, O. Ravelo, and W. Gimenez, “Reduction of non-technical losses by modernization and updating of measurement systems,” in Proc. IEEE/PES Transmission & Distribution Conf. and Exposition: Latin America TDC ’06, 2006, pp. 1–5.

[3] V. J. Hodge and J. Austin "A survey of outlier detection methodologies" Artificial Intelligence Review, vol. 22, pp. 85-126,2004.

[4] A. Pasdar, S. Mirzakuchaki, "A Solution to Remote Detecting of Illegal Electricity Usage Based on Smart Metering", 2nd IEEE International Workshop on Soft Computing Applications, 21-23 August, 2007.

[5] Sam Weckx, Carlos Gonzalez, Jeroen Tant, Tom De Rybel, Johan Driesen, "Parameter Identification of Unknown Radial Grids for Theft Detection"2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe), October 14 – 17, 2012.

[6] Frank VAN DEN BERGH, Petr KADUREK, Sjef COBBEN and WilKLING, "Electricity Theft Localization based on Smart Metering", CIRED 21st International Conference on Electricity Distribution, paper no. 1267.

[7] Shih-CheHuan, Yuan-Liang Lo, and Chan-Nan Lu, "Non-Technical Loss Detection Using State Estimation and Analysis of Variance", IEEE Transactions on Power Systems, Vol.28. No.3, August 2013.

[8] Tomaso Erseghe, Francesco Lorenzon, Stefano Tomasin, Alessandro Costabeber and Paolo Tenti, "Distance Measurement over PLC for Dynamic Grid Mapping of Smart Micro Grids" IEEE SmartGridComm,2011.

[9] K. N. Srinivas and D. Taniguevelane, "Analysis of Smart meter data for Energy Pilferage localization Techniques", IEEE International Conference on Standards for Smart Grid Ecosystem, 6-7 March 2014, Bangalore.

[10] Lance A Irwin, "A high accuracy standard for electricity meters – A White paper" 2011, Schneider Electric.

[11] Marija Boˇckarjova and G¨oran Andersson, "Transmission Line Conductor Temperature Impact on State Estimation Accuracy"1-5 July 2007,Power Tech Conference, IEEE, Lausanne.