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Distribution loss reduction in residential and commercial pilots by using AMI system

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Abstract: This study aims to present a comprehensive distribution loss analysis in typical distribution network of Mashhad in medium and low-voltage networks, which can be useful for network operators. Also the experience with efforts for distribution loss reduction in a residential and a commercial section in Mashhad are reviewed. Unfortunately, non-technical loss is the major part of distribution loss in Mashhad and electricity theft is major source of loss. Therefore, implementing advanced metering infrastructure (AMI) system has a significant influence on the loss reduction because it enables us to detect any types of electricity theft. In this study, results of distribution loss reduction are presented in both residential and commercial pilots through field measurements and DIgSILENT simulations.

1 Introduction

The main function of power system is to supply the load and energy requirements of customers. It is well known that power system faces a big problem of distribution and transmission losses. The main objective of transmission line is to transfer electrical power from generation stations to substations. Distribution substations step the high voltage of transmission line down to lower levels. In other words, the distribution system provides a link between transmission system and customer and provides the power for local use.

In electricity supply to final consumers, losses refer to the amounts of electricity injected into the transmission and distribution grids that are not paid for by users. In general, total losses have two components: technical and non-technical. Technical losses occur naturally and consist mainly of power dissipation in electricity system components such as transmission and distribution lines, transformers, and measurement systems. Non-technical losses are caused by actions external to the power system and consist primarily of electricity theft, non-payment by customers, and errors in accounting and record keeping [1].

Ideally losses in the distribution system should be around 3–5%. However, in developing countries distribution loss is around 20%; therefore, there is an increasing trend in developing countries to reduce technical and non-technical distribution losses [2]. Distribution loss in Mashhad is about 7% in 2015. However, there was no validated data to distinguish non-technical loss from inherent technical loss of the grid. Distribution network operators need to calculate network technical losses for different purposes, such as planning; reducing the network losses; calculating the non-technical losses; and assessing the network efficiency and operational decisions, such as determining the optimum configuration of the network [3]. Therefore, in this paper a complete analysis to calculate technical and non-technical loss separately in distribution system of Mashhad is accomplished.

There are mainly two ways to determine distribution loss of grid: calculation of distribution loss by load flow analysis which needs a complete knowledge about load nodes, as well as, network topology. Another is a routine way of calculating losses of each system i.e. determining the difference of outputs and inputs of the system by meters.

In this paper, both of these methods were utilised for the calculation of distribution loss in Mashhad. This analysis is based on load flow simulation and practical measurement of inputs and outputs by meters both in medium-voltage (MV) and low-voltage (LV) electrical networks.

In the second method, best accuracy of loss determination would be achieved when simultaneous reading of input and output meters fulfilled. This feature can be happen in smart metering system [4]. So all traditional meters of two case studies in a commercial and residential sections were replaced by smart meters and advanced metering infrastructure (AMI) is implemented. Another advantage of AMI system is its ability to identify and monitor non-technical loss of distribution network

AMI data could be effectively used for reduction of non-technical loss especially electricity theft. This opportunity can happen by two methods: big data analysis and event management system that remotely report any tamper in smart meters. For the first case in [5] a method for identifying electrical theft by AMI data is presented. In these methods the collected meter data are used for identifying possible electricity theft situations and abnormal consumption trends [6, 7]. In [8] a game theory model for electricity theft detection by AMI systems data is proposed. The goal of electric utility is to maximise the probability of thief detection.

This paper aims to calculate distribution loss of Mashhad at the first step; subsequently, separation of technical and non-technical loss is accomplished through simulation analysis and field measurement. AMI system is utilised for increasing calculation of loss and non-technical loss reduction.

2 Description of AMI system

Smart metering system is essential for the implementation of smart grid. In this system two-way communication is established between smart meters and meter data management (MDM) system.

Implementation of AMI system is an essential early step for grid modernisation. AMI is not a single technology but it is an integration of many technologies such as smart meter, communication network and management system that provides an intelligent connection between consumers and system operators.

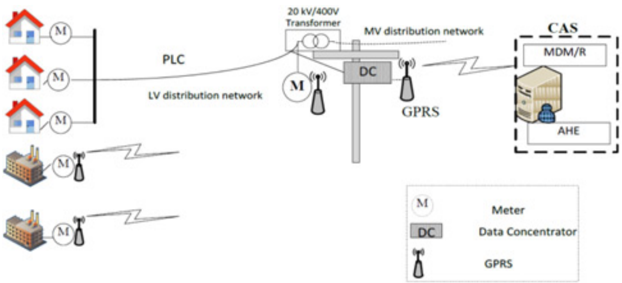

Fig. 1 *Simple structure of AMI system in Iran*

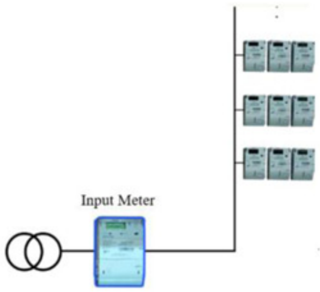

Fig. 2 *Structure of LV network equipped by smart meters*

AMI enables system operator and consumers to use the information that they need to make smart decisions for efficiency enhancement. For example, smart metering system is a powerful toll for the implementation of demand response programmes [9].

Fig. 1 shows a simple structure of AMI system established in Iran [10]. It contains smart meters, data concentrator units (DCU), communication system and MDM. Communication method for LV network is based on PLC and GPRS as local area network (LAN) and wide area network (WAN) respectively.

As discussed earlier AMI system has two positive impacts on distribution loss:

Energy loss calculation: An interesting result of this system is its ability to provide a precise loss calculation by instantaneous measurement of input and output meters. Fig. 2 shows a simple structure of LV network equipped with smart metering system. A main meter is installed at the output of transformer and calculated input energy of system. Smart meters of consumers specify output energy of system. Instantaneous reading of these meters based on (1) calculates daily percentage of energy loss precisely

$$\text{Loss} = 100\frac{P_{\text{in}} - P_{\text{out}}}{P_{\text{in}}} \quad (1)$$

In this equation P_{in} and P_{out} are, respectively, input and output energy registered by smart meters.

Non-technical loss minimisation: Another opportunity of AMI is that any sources of non-technical loss like electricity theft could be notified. Any deviation and change in smart meters are identified and reported to MDM. Thus, meter frauds can be removed.

In this paper in order to minimise non-technical loss of system and to have a validated view of distribution loss of LV network, traditional meters of the commercial and the residential LV network are replaced by smart meters.

3 Loss reduction in commercial pilot

A commercial pilot that was probable for electricity theft and high non-technical loss was selected and distribution loss of pilot was measured before the project as 16%. Number of consumers of this pilot are 37.

This project aimed to remove technical and non-technical loss of LV network by following considerations:

Non-technical loss removal: The access of consumers to smart meters was removed and the meters were installed on the top of the pole just below pole-mounted transformers. The fuse is accessible for the consumers in the store. This approach removes non-technical loss as a result of prevention of meter frauds.

Technical loss removal: Also a reconfiguration of transformers was applied and two large capacity transformers were replaced by five small ones (100 kVA). Also LV network is removed as a result of transmission of meters to top of the poles.

To assess pilot, traditional meters of consumers did not collect and the consumption of each consumer was compared through smart and traditional meter. Table 1 shows a brief overview of results. It is observed that return of investment in this pilot is about 17 months.

Another approach for commercial consumers is installing smart meters for towers that are equipped with bus-duct technology. In addition to meter reading of consumers that are located at the stages, daily calculation of loss through designed software can efficiently lead to electricity thief, if exists. Fig. 3 shows daily loss rate of a tower for example.

Table 1 An overview of return of investment assessment

date of measurement	17 April to 22 April 2016
duration of measurement	6 days
number of meters	37
number of faulty meters (deviation of 5–20%)	14
number of fraud meters (deviation of more than 20%)	6
energy saving in measured duration	1208 kW h
estimated annual energy saving	73,400 kW h
estimated annual money saving(0.3 $/kWH)	22,020$
whole investment	29,700$
return of investment	17 month

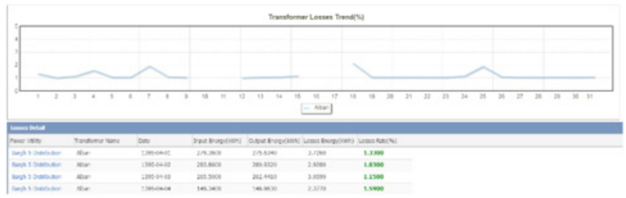

Fig. 3 *Daily loss of a commercial tower*

4 Loss reduction in residential pilot

Residential pilot consists of 437 consumers that are fed from two transformers. Table 2 represents some specifications of distribution network of the project.

In this project, first of all, the distribution loss in the section was measured and analysed before implementation of AMI. Since this section has a relative high distribution loss, it was decided as a

Table 2 Distribution network specification of project

Transformer type	Number of consumers	Length of LV network (m)
pole-mounted transformer	240	1,582
substation transformer	197	1934
total	437	3516

Table 3 Results of loss reduction project<CE: Table has been renumbered. Please check.>

Transformer type	Distribution loss before project	Technical distribution loss	Distribution loss after project
method of calculation	Synchronous field measurement	Simulation with DIgSILENT	Online data of smart meters
pole-mounted transformer	6.9%	2.13%	2.3%
substation transformer	11.6%	2.98%	3.2%
total	9.2%	2.48%	2.7%

Fig. 4 *Daily loss of pole-mounted transformer of pilot*

candidate for loss reduction project. Distribution loss of this section was measured by synchronous reading of meters for a 15-day period and it was 9/2%.

Afterward consumer meters were replaced by smart meters. AMI system enables us to calculate distribution loss precisely because they communicate electrical data every day.

In another study, simulation analysis was carried out to distinguish technical and non-technical loss of pilot. Simulation analysis is very precise because load and voltage data required for simulation was captured from real data of smart meters. Table 3 represents results of loss reduction in this project.

It is observed that distribution loss of section reduced from 9.2% to 2.5%. This reduction is due to non-technical loss minimisation as a result of smart metering system. All of traditional meters were tested to identify error or frauds. Following reasons have most impact on non-technical reduction:

- Electromechanical meters are about 30% of traditional meters. It is proved that this type of meters has an average of 2% error.
- Overall, 14 consumers had electricity theft with more than 70% error in meters.
- There exists a consumer (bicycle station) that does not have any meters. Also street light of street was out of meter.

Daily loss rate calculation is feasible through AMI software. Fig. 4, for instance, shows daily loss of pole-mounted transformer. This analysis proved that in the typical LV network of Mashhad, which is aluminium 4×75 mm self-supporting cable, distribution loss is about 2.5%.

5 Simulation results of loss calculation in a MV feeder

In another analysis 20 kV feeder was simulated in DIgSILENT and distribution loss of MV feeder was calculated. LV transformers that were equipped with smart meters were the nudes of loads and required data was captured from real-time smart meters. Fig. 5 shows hourly load data of a sample transformer for 3 days that are measured by smart meter.

The distribution loss was calculated as 1.9% which contains line and transformer loss. Fig. 6 shows 20 kV network of simulated feeder.

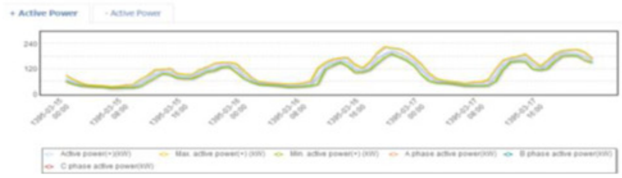

Fig. 5 *Hourly data of transformer that are used in DIgSILENT for load flow analysis*

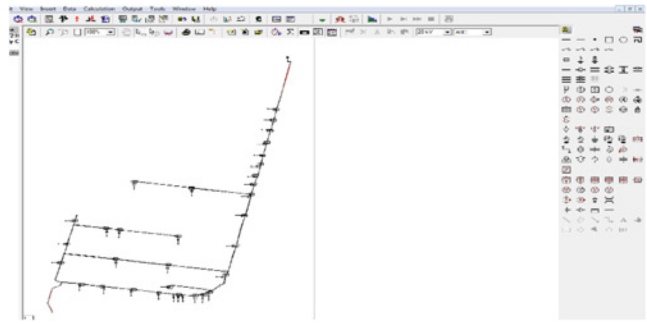

Fig. 6 *Schematic of 20 kV feeder simulated in DIgSILENT*

6 Overall distribution loss analysis of Mashhad

Distribution network operators need to calculate network technical losses for different purposes, such as planning; reducing the network losses; calculating the nontechnical losses; and assessing the network efficiency and operational decisions, such as determining the optimum configuration of the network. In the earlier sections energy loss in LV and MV network were obtained through practical measurement and load flow simulation in DIgSILENT. It was indicated that energy loss of a typical residential LV network is about 2.5% and typical loss of MV network containing transformer and MV feeder is about 1.9%. Overall distribution efficiency could be deduced based on the following equation:

$$\eta_{\text{Total}} = \eta_{\text{LV}} \eta_{\text{MV}} \tag{2}$$

In which η_{LV}, η_{MV} are respectively LV and MV efficiency and we have

$$\text{Loss} = 100(1 - \eta) \tag{3}$$

So total loss in a typical distribution network of Mashhad is about 4.3%.

7 Conclusions

A comprehensive analysis on distribution loss is presented in this paper. First of all, distribution loss in a residential and a commercial LV network was calculated in both field measurement and load flow simulation study. AMI system was utilised in order to enhance accuracy of measurement of energy loss of distribution system in these pilots. This opportunity is one of the various advantages of AMI system that can be achieved by its ability to read input and output meters of system simultaneously. Also AMI minimises non-technical loss of system. A load flow analysis based on simulation analysis was accomplished to calculate MV network loss in DIgSILENT. These results indicate that distribution loss in LV network is about 2.5% and MV network is about 1.9%; therefore, it can be deduced that distribution loss in a typical network in Mashhad is about 4.3%. Existence of non-technical loss will cause deviation and can be an alarm for distribution network operators

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