REAL TIME PURCHASE AND SETTLEMENT OF DISTRIBUTION LOSSES

Anssi SEPPÄLÄ
Enease Oy – Finland
anssi.seppala@enease.fi

Juha-Heikki ETULA
Fortum Distribution – Finland
juha-heikki.etula@fortum.com

Sirpa FORSMAN
Fortum Distribution – Finland
sirpa.forsman@fortum.com

Joachim HÖGBERG
Fortum Distribution – Sweden
joachim.hogberg@fortum.com

ABSTRACT

This paper describes a methodology to purchase distribution losses real time from the power market. The real time hourly loss is calculated with a loss function. A method for evaluation of the loss function using billing data and energy data from AMR and conventional kWh-meters is described. This methodology is applied for Fortum Distribution Finland networks of 613 000 customers and several other Finnish utilities.

INTRODUCTION

The power distribution network is a large energy consumer itself. About three to five percent of the total energy is lost in the distribution network. The major share of the loss energy is heating conductors, transformers, meters and instruments without kWh-metering. Furthermore there are non-technical losses like stealth as well as administrative losses caused by data processing errors.

It is impossible to directly measure the loss energy because of the size and complexity of the distribution network where the loss energy is spread all over. The traditional approach to loss estimation is to use the network data from conductors, lines, sub-stations etc. The modern network information systems (NIS) can estimate the loss energy [1], but the lack of load data is a big source of errors, and there is no feedback to the metered load data in the estimation.

The demand for more accurate loss energy estimation comes from two directions: Firstly the development of the energy efficiency of the distribution network requires accurate loss estimation to measure the real achievement of energy saving. Secondly, the de-regulated power market requires the distribution operators to be neutral to competing suppliers. The purchase and settlement of the distribution losses must treat all the energy suppliers equally. To be able to report sales accurately the purchased loss energy must be equal to losses consumed in the network. If the purchased loss energy is too much, the balancing supplier earns extra money at the cost of distribution customers. If the purchased loss is too little, the balancing supplier loses money.

The distribution network operator purchases the loss energy from the power market. The loss energy must be defined on hourly level to achieve market price and handle the energy in the balance settlement in the power market [2]. While the price of the energy becomes higher and more volatile, the interest for more accurate loss estimates grows.

THE DEFINITION OF LOSS ENERGY

The loss energy is all the energy that is fed to the distribution network but *not* delivered to the customer load points and energy meters. The customer load points include also the distribution company’s own metered energy use:

$$Loss\ energy = Input\ energy - \sum Loadpoint\ energy$$

The input energy (feeders and generation) is hourly measured and data is easily accessible. Normally, the largest customer loads are hourly metered. However there are a large number of customer loads that are monthly metered or conventionally metered in uneven time periods ranging from one to few years.

An automated meter reading system (AMR) connected to every load point would be an ideal solution to obtain load point energy. However, because of the cost optimisation, the AMR systems usually do not cover all the load points, and conventional meters are used at least for metering minor loads.

When calculating the loss energy, it is critical that the algorithm calculating the total of the load point energy can use all the energy information from the network. Otherwise the missing data is cumulated into the loss energy, and the accuracy of the loss energy worsens.

The comprehensive source for load point energy data is the distribution operator’s customer information database, billing data and the meter reading database.

OVERVIEW OF THE METHOD

In the Nordic power market energy purchases are done real-time, and the hourly balance between the suppliers is settled every working day. The final settlement between the suppliers is eventually made in 14 days. To achieve metered loss data in such time window would require a complete hourly reading from all load points. Such a complete hourly metering system with high reliability would be very expensive and therefore the optimal solution is to use the loss function estimating the hourly loss energy.

The loss function calculates the hourly loss energy from the hourly network input energy:

$$\begin{aligned}&Hourly\ loss\ energy\\&= Loss\ function(hourly\ input\ energy)\end{aligned}$$

The network input energy is hourly metered and available for the daily balance settlement. Thus also the hourly loss energy is always available for the balance settlement after the computation of loss function.

The loss function is estimated from the loss percent (loss%). The loss% is calculated from the loss energy from the loss analysis and input energy of the network:

$$loss\% = 100 \times \frac{annual\ loss\ energy}{annual\ input\ energy}$$

The time period of the calculation of loss% depends on the meter reading practices. There must be majority of the meter reading data collected from the load points.

The hourly loss purchasing consists of the following phases (Fig 1):

1. Initially estimate the loss% and loss function.
2. Calculate the input and loss forecasts.
3. Daily make the hourly loss calculation with loss function and input energy for the loss supplier and balance settlement.
4. Periodically collect energy and load point data to re-calculate the loss% and make the final settlement of the loss energy.
5. Update the loss% and the loss function and go to phase 2.

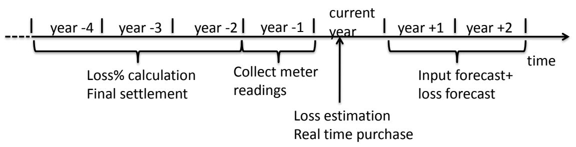

Fig. 1. The phases of loss purchasing in time line. There are both conventional kWh-meters and AMR meters in the network.

Usually there are conventional kWh-meters and AMR meters. Because conventional kWh-meters are read once a year, the rule of thumb for the length of loss analysis period is at least three years. Thus kWh-meter reading collecting takes in addition at least one year after the analysis period.

If all the load points are covered by AMR and read daily or monthly the final settlement of the losses could then take place even next month.

THE REALTIME DAILY PURCHASE OF LOSSES WITH LOSS FUNCTION

The loss function estimates the hourly loss from the hourly network input energy. The loss function represents hourly loss as the sum of idle losses and resistive losses:

$$P_L(t) = P_0 + k * P(t)^2$$, where

$P_L(t)$ = Loss at hour t
P_0 = Idle losses of the network
$P(t)$= Input at hour t

The idle loss power P_0 is the total of transformer idle loss power in the network.

The coefficient k is calculated so that the loss function results to the loss% over the period T that is usually one calendar year or multiple years:

$$k = \frac{[0{,}01 \times loss\% \times \sum_{t\in T} P(t)] - \sum_{t\in T} P_0}{\sum_{t\in T} P(t)^2}$$

Example of hourly input and loss is shown in Fig 2.

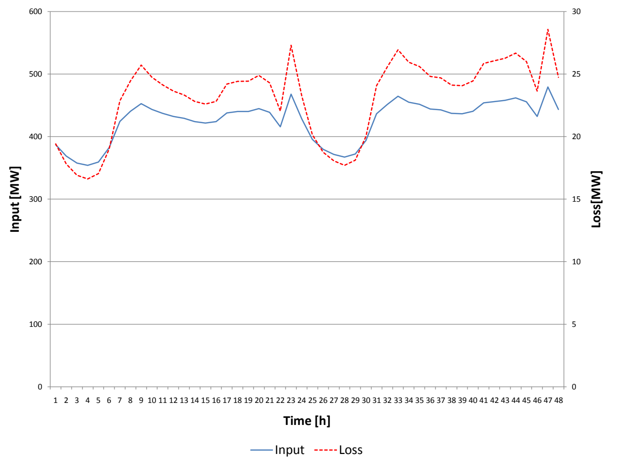

Fig. 2 Input (left axis) and loss (right axis) calculated hourly with the loss function for two days.

The loss energy must be forecasted one or two years ahead for price hedging. The network input profile is forecasted first, and the loss profile forecast is then evaluated using the loss function.

The long-time forecasting of the loss profile is done by creating a long time load model for the network input load. The elements of the input load model are monthly 24 hour load profiles for working day, Saturday and Sunday. The temperature correlation is calculated for each hour from the load and temperature history. Finally the load model is evaluated using long time temperature statistics to get the hourly loss load forecast (Fig 3).

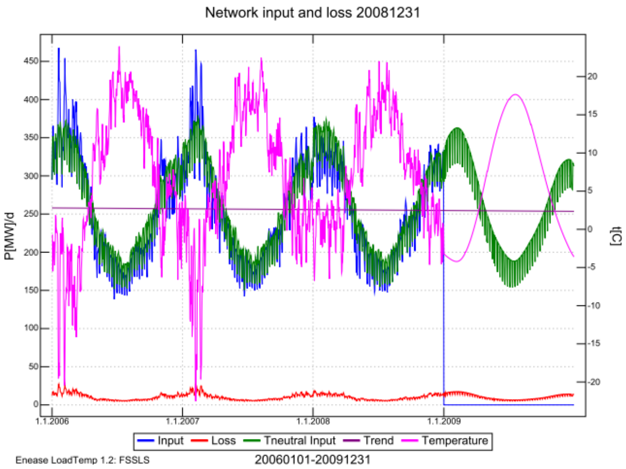

Fig. 3 The input (blue) history from 1.1.2006 to 31.12.2008 and forecast (green) from 1.1.2009 to 31.12.2009. Loss (red) calculated from input with loss function.

THE ESTIMATION OF THE LOSS%

The loss% estimation requires that all the load data is transformed into uniform time intervals. There are several intervals to choose: hourly, daily, weekly or monthly resolution. In our experience the daily resolution is found the best because date is known for all meter readings.

The daily load data is put into a *load grid* (Fig 4) where each row is for one load point and one column for one day. Thus the load grid has dimension of the number of load points times the number of days. For example 100 000 rows and 2 191 columns table for one distribution network of 100 000 load points and 6 years time period.

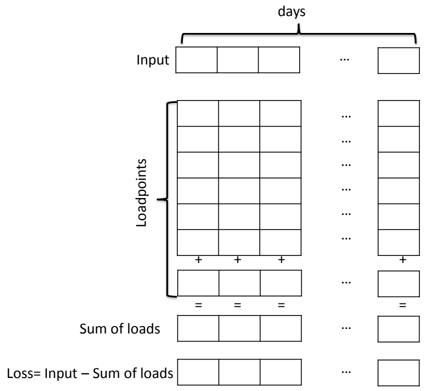

Fig. 4 The load grid. The sum of loads is computed in the grid and then subtracted from the input. The result is the loss energy.

The total of load point loads is calculated by summing the columns of the load grid.

The load point energy data is retrieved from the billing system and meter database of the distribution company. The data is meter readings or energy consumptions between dates. For each load point the metered energy is transferred to daily loads and put into the calculation.

Transferring energy data of longer periods to daily loads requires estimation of the load curves in order to split the meter reading interval to daily energy[3]. The best result is achieved by applying profile that is calculated from the difference between the input load and the hourly metered loads. For the hourly metered loads the load profile is estimated directly from their metered data.

Outside the reading intervals the load is estimated using the annual energy estimate (AEE) for each load point. The AEE is usually calculated by the invoicing system from meter readings and billing history.

The accuracy of the loss% estimation depends on the length of the analysis. The longer the analysis period is, the more accurate the loss% is because the error caused by the asynchronous kWh-meter reading intervals is limited by the average reading interval at the both ends of the analysis period.

An example of the 6 years analysis of loss% from the load grid is shown in Fig. 5. In this network case the loss% is quite stable varying arount the 4% value.

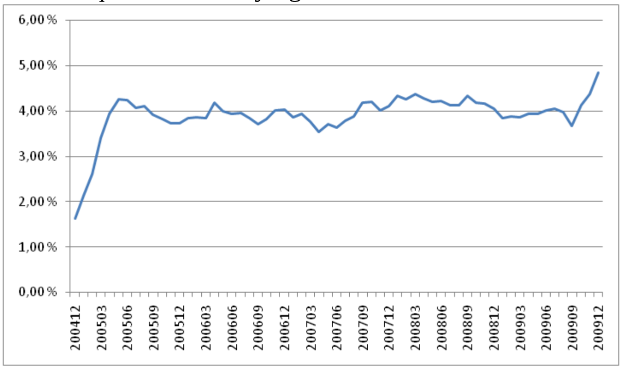

Fig. 5 The loss% calculated from the load grid as a moving average of one year's window 2005...2009. The analysis period is 2005...2009. The estimation period is 2006...2008.

The loss% for the 2006...2008 period is the average of the curve in Fig 5.

The Data Quality Control

The calculation result of the loss% is very sensitive to errors in the source data. Cross checking is needed to ensure that there is enough data from all load points and the data is correct.

The backbone of the loss% analysis data is the uniquely coded list of all delivery load points of the network, the dates when they were connected to the network and the dates disconnected from the network. An annual energy estimate is also imported from the billing system with the load point information.

The energy data from the billing system must include the load point, start date, end date and energy for each metered interval. There will be several records of energy data for each load point.

The data quality control includes finding load points where energy data is missing and comparing energy to the annual energy estimate. Also bad and unrealistic data is checked by computing statistic from the load data and checking extreme values.

After the quality of data is carefully checked, the loss table will be populated and the loss energy calculated.

While the load data is transferred to the load grid, the data is marked estimated or metered. Each cell of the load grid is marked as ”metered” if the value of the cell is result of metered energy or ”estimated” when the value of the cell is estimated from the annual energy estimate.

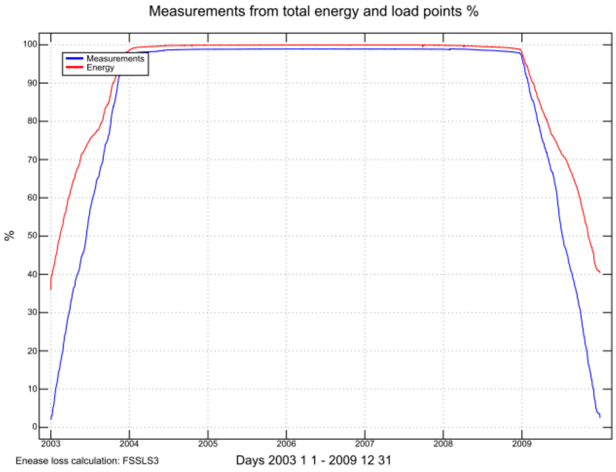

Fig. 6. The ratio of measurements and estimates during the loss% analysis period. The both ends are estimated while in the middle the meter readings cover all load points. Red line represents energy and blue line load points.

THE FINAL SETTLEMENT OF THE LOSS ENERGY

Depending on the business practices the calculation of losses with the loss function may be sufficient if the loss% from the analysis is almost the same as the loss% used in loss function.

If the loss% varies a lot, it is relevant to settle the final loss energy. The real time purchased loss energy is then compared with the new loss calculation and the final settlement is funding or re-funding between the distribution operator and the loss energy supplier.

THE FORTUM DISTRIBUTION CASE

Fortum Distribution network in Finland has 613 000 customers, and the network is divided to eight distribution areas. The areas are geographically in different locations and have different characteristics and features in terms of size, outdoor temperature and customer behaviour. The largest area is about 150 000 customers and the smallest 32 000 customers.

The data flow of the process is shown in Fig 7.

The hourly network input data for each area was retrieved from the Fortum Distribution energy management system (EMS). Also, the hourly outdoor temperature for the input load modeling was retrieved for each area.

The load data for each load point was retrieved from the Fortum distribution's customer information and billing system (CIS) for each area:

The load point data:

- load point id
- connection date
- disconnection date
- annual energy estimate
- customer category

The load data for each metered load:

- load point id
- start date
- end date
- energy
- supplier

The hourly metered data was retrieved from the meter reading database.

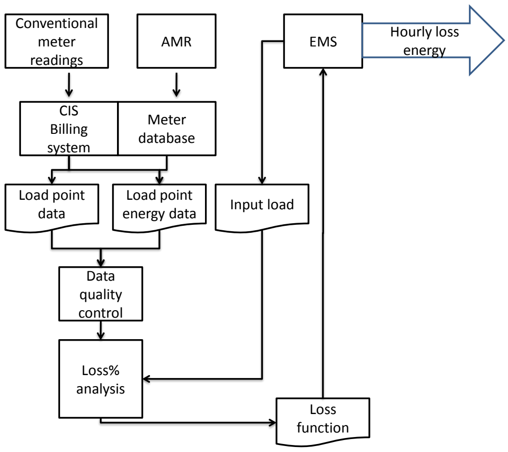

Fig. 7 The loss analysis and estimation data flow.

Both the input data and the customer load data was collected from years 2003 ... 2009.

The loss analysis was done in 2010. The data was loaded into a 64bit workstation with Enease loss% analysis software.

The loss% was estimated for each area separately for the three year period 2006, 2007 and 2008. The loss% varies from 2,76 % for city areas to 4,64 % for rural areas. The losses of the main 110/20 kV transformers are not included.

The loss% and loss function was defined for each of the eight areas. Two examples of the loss functions for two areas "EP" and "LS" are given here:

For area "EP" of 60000 customers, total annual input 1091 GWh, max demand 255 MW, loss% = 3,62 % and loss function:

$$P_{L,EP} = 1{,}171\ MW + (0{,}0001959\ MW^{-1}) \times P_{EP}^2$$

For area "LS" of 158000 customers, total annual input 2285 GWh, max demand 501 MW, loss% = 4,05 % and loss function:

$$P_{L,LS} = 2{,}290\ MW + (0{,}0001138\ MW^{-1}) \times P_{LS}^2$$

The input load and loss energy was forecasted for 2011 for each area.

The hourly loss energy is calculated with these loss functions daily in the Fortum's energy management system. The procurement of the loss energy is done monthly with the supplier. The final settlement will be done after the next loss% analysis.

Until the end of 2013 most of the conventional kWh-meters will be replaced with AMR meters. Then the final settlement of loss energy can be scheduled monthly or annually.

CONCLUSIONS

The procedure of purchase and settlement of loss energy with loss function presented in this paper are used in several utilities in Finland. The required accuracy for loss energy has been achieved.

The advantage of this method takes benefit from all meter readings, and the AMR can be fully utilised to improve the accuracy of the loss energy estimation and purchasing process.

REFERENCES

[1] M. Kinnunen, E. Lakervi, S. Kärkkäinen, 2003, "Estimation of Distribution Network Losses and Their Value in Competitive Electricity Market", CIRED 2003, Barcelona

[2] A. Diop, D. Dercle, 2005, "Losses Modelling for Distribution Networks", CIRED 2005, Turin

[3] A. Seppälä, 1996, "Load Research and Load Estimation in Electricity Distribution". VTT Publications 289. Technical Research Centre of Finland.