DISTRIBUTION GRID PLANNING AND ANALYSING USING SMART METERING DATA

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ABSTRACT

Smart grid is future of power distribution system. One of the most important parameters of smart grid is smart metering system. Smart metering is penetrating in distribution grid increasingly in many countries. Smart meter data present great amount of data which can be very useful in distribution grid analysis and planning, if used properly. In this paper smart metering system in Public Electric utility "Elektroprivreda HZ HB, Mostar", Bosnia and Herzegovina will be presented. Some benefits of using smart metering data in distribution grid planning and analysing would be described.

INTRODUCTION

Evolution of distribution grid is focused on smart metering. Smart metering is mainly focused on improving quality of service. Today, smart meters located at houses serve to improve customer awareness and to enable new smart home services [1]. According to [2], smart metering improves company's ability to detect and locate electricity theft. Model developed in [2] serves to estimate the magnitude of theft once detected. In [3], smart metering using in detection of wrongly connected consumers is presented. Algorithm presented in [3] identifies consumers which are incorrectly placed in the GIS grid topology. Algorithm serves for finding correct grid topology tree. Smart meters data use in load profiling and clustering is presented in [4-5]. In [4], consumption data is used for updating and clustering of consumers. Researchers in [5] analyse necessity of massive use of smart meters due load profiling and clustering possibilities. Using smart meter data for fault indication, power quality monitoring and interruption reporting is presented in [6]. Statistical data analysis of low-voltage (LV) feeders in terms of voltage, currents and power factor is presented in [7]. Results of different seasons are compared. Modelling of electrical distribution feeder using load values in time period is presented in [8]. Results obtained in [8] show that distribution feeder using smart meter data can be modelled with high accuracy. Presented model can be used for distribution grid state estimation, fixing topology errors and voltage regulation. In [9], an integrated load and state estimation algorithm for MV grid was developed. Algorithm serves for defining of grid operating state. Thus, it can improve operation and control of distribution grid. Optimization of transformer selection using smart meter data is presented in [10]. It is expected that it is possible to reduce the asset investment for transformers using smart meter data. Electrical tariffs modelling using smart meter data is analysed in [11]. Using historical data, representative load diagrams of consumers were created. Some general opportunities of smart meter data analysis are presented in [12]. According to [12], hourly load profiles of consumers are very important for distribution grid planning. Literature [13] describes case study of distribution grid planning using smart meter data. In [13], grid planning using load data values and load flow analysis is presented. The goal was to reconsider Velander formula which is quite robust. Middle voltage (MV) distribution grid planning approaches are elaborated in [14]. Those approaches can result in mitigating of conductor overcapacity, voltage drops and technical losses.

SMART METERING SYSTEM IN POWER UTILITY ELEKTROPRIVREDA HZ HB

Smart meters in Elektroprivreda HZ HB increasingly penetrate in distribution grid and by today those are installed in each transformer stations (TS) MV/LV and at some consumers (industry primary and some buildings/houses). First, smart meters were installed in TS MV/LV. Later, industry consumers were target. Today, smart meters are installing in houses and buildings. It is an ongoing, expensive and long term process. Great amount of data from those meters is quite challenge for practical use. Existing smart metering system infrastructure in Elektroprivreda HZ HB is presented in Fig. 1.

Fig. 1. Existing smart metering system infrastructure

Smart meters in exploitation at concerned utility give informations about electrical energy, power, frequency, power factor, voltage and current. Time period of collected data can be: 1 min., 5 min., 10 min., 15 min., 20 min., 30 min. and 60 min. Communication technology is GSM/GPRS for communication between meters and server (through provider of mobile communications

services) – Fig. 1. Communication protocol is TCP/IP. PLC S-FSK (Power Line Carrier Spread Frequency Shift Keying) communication technology is in use at communication level consumer-TS (Fig. 1.). This communication is through LV grid. Communications used in exploitation have proved as satisfactory.
Installation procedure of smart meters for concerned utility (distribution grid) is presented in Fig. 2.

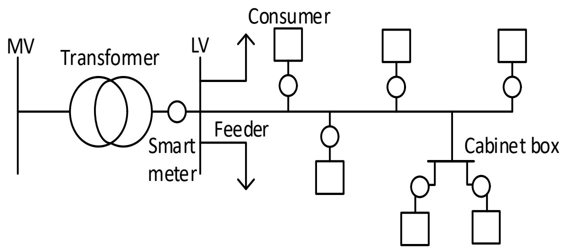

Fig. 2. Installation of smart meters in concerned distribution grid

Smart meters are usually located in places as shown in Fig. 2. Smart meters are located at LV side of TS MV/LV mandatory. Today, smart meters are locating at each consumer gradually. There are no meters at sources of feeders.

SMART METER DATA USE FOR DISTRIBUTION GRID PLANNING AND ANALYSING

In beginning of their installation, smart meter data were usually used for:

a) Remote reading of industrial customers (later small consumers like houses too) in order to reduce human reading errors and decreasing costs of reading,
b) Limiting peak power of industrial consumers (in accordance with permission) and
c) Identification of TS with great loses – potentially non-technical losses location by comparing delivered and consumed electrical energy.

Possibilities of using smart meter data are quiet greater than listed above.
Using smart meter data for distribution grid planning and analysing is quite new trend in concerned utility. The problem is how to use those data for extraction of smart findings in distribution grid planning and analysing. The problem is not unilateral. Some of applications of using smart meter data in distribution grid planning and analysing, in case of Elektroprivreda HZ HB, will be presented in paper. Several useful application directions will be introduced.
Directions can be divided in several items:

a) Load profiling,
b) Grid losses analysing,
c) Peak power analysing,
d) Consumption forecasting,
e) Slow voltage variations – voltage quality analysing
f) ENS and VoLL calculation and
g) Statistical approach for smart meter data.

Load profiling

Generally, load profiling is base opportunity of smart metering in distribution grid. Fig. 3. presents example of active power (kW) time series for 1year period on 1-hour base (from 1 January to 31 December). This load profile is sum of smart meters measurements at LV side for 43 TS MV/LV (2 MV feeders). Active power as shown in Fig. 3. presents load profile for one small community on 1-hour base. Identical principle is possible for only one feeder, a few TS MV/LV in one area, only one TS MV/LV etc.

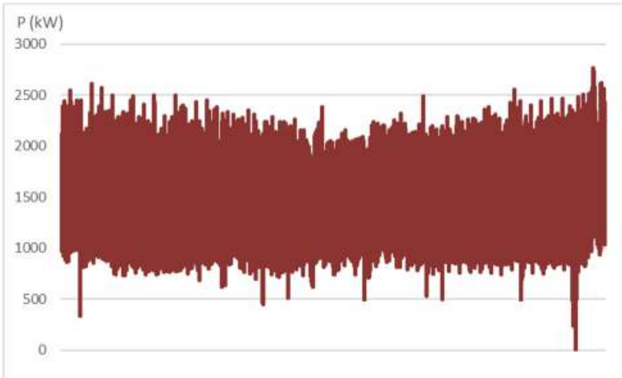

Fig. 3. Active power time series for 1-year period on 1-hour base interval.

From Fig. 3. period of peak power is visible and it is at the end of year. Further, a period of failure at all area is visible (transformer failure in this case). Basic statistics parameters of presented time series are shown in Table I.

TABLE I. BASIC STATISTICS PARAMETERS OF ANALYSED DATA

Statistics Parameters	
Mean (kW)	1536.84
Median (kW)	1669.54
Mode (kW)	1943.34
Standard Deviation (kW)	434.50
Skewness	0.344
Minimum (kW)	0
Maximum (kW)	2761.50

This direction enables analysis of load profile for each TS MV/LV, whole settlement, one area as in this case etc., for each period of year.

Grid losses analysing

This direction is useful for some TS where smart meters are placed at consumers side, beside LV side of TS. Then, losses can be easily detected and their values can be tracked month by month or by periods (winter, summer). That can help in commercial losses detection (beside findings about technical losses). Fig. 4. presents energy consumption on monthly base at one TS MV/LV. "Transformer" curve presents data from smart meter at LV side of TS MV/LV and "consumers" curve presents sum of energy consumption from smart meter data of all consumers at corresponding TS. Data are on monthly basis. Difference between these curves presents sum of technical and commercial losses at this TS area.

Sum of technical and commercial losses in percent value is presented in Fig. 5. It is clear that at winter period losses are much higher than in summer period. It is high probability of commercial losses existing in this area (subjected TS). Inspection of subjected TS has shown high share of electrical heating equipment what contributes to this statement. Further inspection of consumers should be performed for detecting electrical theft.

Knowing losses (absolute and percent values), investment plans with priorities can be set for LV grids with high level of losses. The goal should be loss minimization (technical and commercial losses).

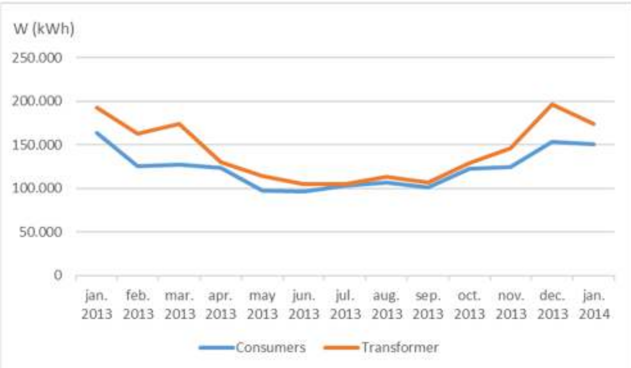

Fig. 4. Energy consumption on transformer and consumers side.

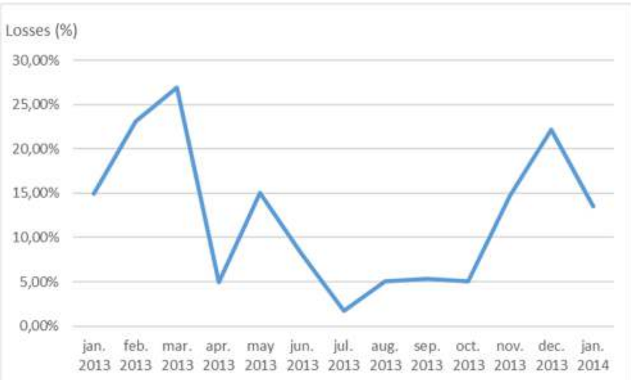

Fig. 5. Sum of technical and commercial losses at this TS area.

Peak power analysing

Fig. 6. presents peak power (kW) for individual consumers at chosen TS (presented with their ID number on abscissa). Those TS are feed from one feeder in rural area. Peak power is ratio of maximum TS active power of 15-minute interval in 1-year (data from smart meter) period and the number of active consumers on that TS. Even these TS are at about similar area (one rural feeder consuming a few villages) there is difference in peak power results.

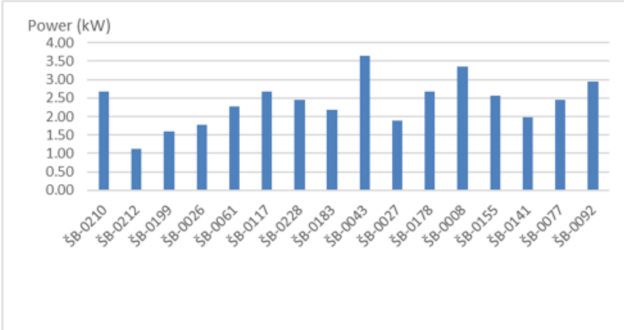

Fig. 6. Peak power (kW) for individual consumers at chosen TS.

Minimum peak power is 1.11 kW, maximum is 3.65 kW and average for whole feeder is 2.39 kW. It is a quite difference reaching 200% difference in percent. These differences between areas are due to heating/cooling systems, life habits, existing of commercial losses etc.

Smart meter data can give a relevant informations about peak power in certain areas what is helpful in distribution grid planning in similar areas in purpose of peak power determination. Knowledge of consumer types is requirement for confirmation of similarity. These data about peak power are data from live distribution grid and should have much more weight than theoretical approaches like using Velander's formula etc. This approach can have use in transformers rated power sizing, feeders conductor sizing etc. for new planned TS (based on similarities with existing TS).

Consumption forecasting

Fig. 7. presents energy consumption sum (several TS MV/LV) on monthly base at one industry area with several factories. That area has property of high propagation in capacities. The results of energy consumption are presented for 4 years period (blue line). It is visible that in this case simply linear regression can describe energy consumption in timeline with coefficient of determination (R^2) 0.92. On trace of that knowledge, consumption forecast is performed for period of 3 years with upper and lower confidence bound of 95% (red lines).

Fig. 7. Energy consumption - history and forecasting.

From Fig. 7. is obvious that for this area, consumption forecasting has linear trend. A reliable short term forecasting of consumption for this area can be done. This can be useful for electrical energy consumption analysing and planning of consumption for different consumer types and areas. These data can be important for investment planning in distribution grid capacities (mid/long term distribution grid planning/development).

Slow voltage variations – voltage quality analysing

Voltage values can be presented in 10 minutes interval. It is in accordance with EN 50160:2011 issued by CENELEC. Slow voltage variation values in 10 minute intervals are probably the most important voltage quality parameters. Fig. 8. presents voltage profile (phase voltages) for 2-month period in 10 minute intervals at chosen customer.

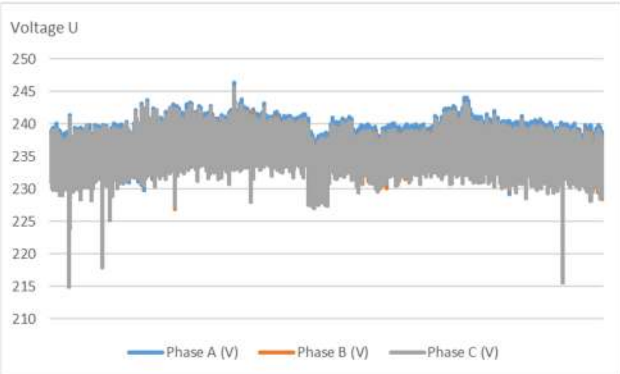

Fig. 8. Voltage profile for 2-month period in 10 minutes interval for chosen customer.

From Fig. 8. is visible that for each period, voltage drop was not under 90% of nominal value. In accordance with EN 50160:2011, voltage drop can be 5% of one-week period under 90% or nominal value (for 10 minute intervals). Monitoring of voltage values is indicator for investment/reconstructing plans. Localization of areas with presence of great voltage drop is trigger for investment/reconstruction in distribution grid of that area (replacement of conductors with the one with greater cross section, planning of new TS etc.).
Basic descriptive statistics parameters of voltage profile, such minimum value, maximum value and mean value for this case study are presented in Table II.

TABLE II. DESCRIPTIVE STATISTICS FOR PRESENTED VOLTAGE PROFILE

	Phase A (V)	Phase B (V)	Phase C (V)
Minimum (V)	218.13	216.78	214.9
Maximum (V)	246.31	245.6	245.6
Mean value (V)	236.43	235.64	235.50

ENS and VoLL calculation

One approach for energy not supplied (ENS) calculation is presented in this part. This approach is based on smart metering data. One TS with measured parameters from smart meter is chosen (for 1-year period, on 10 minutes interval). This TS has 64 consumers (family houses). From smart meter data, average active power for TS of 65.7 kW is calculated.
Analysis of 10 minute intervals of voltage values was performed. Periods without registered voltage present power-cuts on chosen LV grid. Power-cuts can present failure (e.g. transformer failure, MV grid failure or HV grid failure), but it can be scheduled maintenance too (e.g. MV grid maintenance). The goal was to find ENS and associated value of lost load (VoLL). Presented analysis for chosen TS power-cuts outcomes in the following data:

a) Power-cuts were detected in 23 days (approximately 1 failure in 16 days),
b) Total power-cut for this TS lasted 32 hours/a and
c) Average power-cut lasted 83 minute.

Now, ENS was trivial calculated for this purpose as product of average active power for subject TS of 65.7 kW and total power-cut period of TS (32 hours/a). It was obtained that ENS/a for this TS is 2102 kWh. VoLL values are not specified for Bosnia and Herzegovina but data is taken from neighbouring Croatia of 2.56 EUR/kWh. So, trivially calculated VoLL for subjected TS is 5382 EUR for subjected year.
This calculation, even trivial, can give clearly and initial indicators for reliability of LV grid. VoLL can be one of indicators for creating investment/reconstruction plans of LV grid. Analysis can be extended on feeders too.

Statistical approach for smart meter data

Statistics can be powerful tool for analysing of great amount of data. Figure 9. presents probability density function (PDF) of 10 minute intervals of voltage data in chosen TS for 1 year. Bins are chosen on base of voltage range. Beta distribution quite good presents voltage data according to Kolmogorov-Smirnov test.

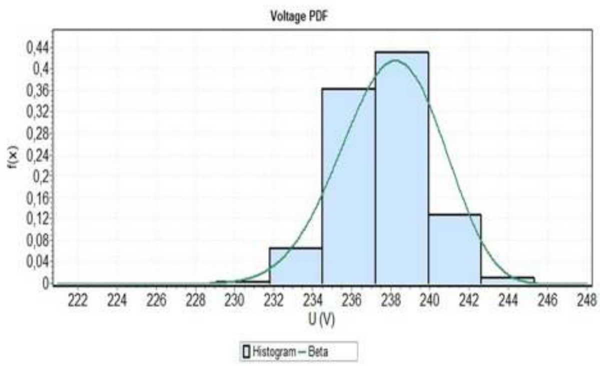

Fig. 9. Beta PDF of 10 minute intervals of voltage data in chosen TS.

Proposed approach can give informations about voltage quality data at TS level. Further, with this approach based on PDF and associated cumulative distribution function (CDF), different data analysis are possible.
In this case of Beta distribution, for example:

a) Voltage has higher value than nominal (231 V) for 99.57% of 10 minute intervals/a,

b) Voltage is increased over 5% of nominal value (242.6 V) for 2.53% of 10 minute intervals/a and

c) Voltage is 97.04% of time in interval 231 V≤U≤242.6 V.

With this approach it is possible to have informations about time period of under/overvoltage, voltage variations etc.

This approach is applicable too for other parameters like power, current etc. Some other distributions can fit data too.

CONCLUSIONS

In this paper, smart meter data analysing for distribution grid planning and analysing is presented in case of Elektroprivreda HZ HB, Mostar. Primal benefits of smart metering were in scope of remote reading in order to reduce human reading errors and decreasing costs of reading, limiting peak power of industrial and in identification of TS with great loses (potentially non-technical losses). But, possibilities of using smart meter data are quiet greater than used primary. Here, some of those possibilities in case of distribution grid planning and analysing are presented. Those possibilities are in scope of: load profiling, grid losses analysing, peak power analysing, consumption forecasting, voltage quality analysing, reliability calculations and statistical analysing. All those possibilities are validated with examples-practical case studies. Smart using of smart meter data in one utility can help in distribution grid planning and analysing. This help can be in terms of decision making for investment/reconstruction plans, plans for losses reduction, consumption forecasting, reliability analysing etc. Smart meter data, if used properly, can make easier managing of distribution grid. Further work will be in investigation area of correlation between existing tariffs and energy consumption. More detail implementation of smart meter data in reliability analysis will be investigated. Statistical analysis of smart meter data is too subject of research by authors.

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