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NOVI PRISTUP SMANJENJU GUBITAKA POMOĆU ANALIZE MREŽE I UVIDA U ODNOS ENERGIJA - OPTEREĆENJE

SAŽETAK

Operatori distribucijskog sustava suočeni su sa više od 200 milijardi dolara godišnje u gubicima i krađi što se postepeno povećava za 2,5% godišnje dok su istovremeno pod pritiskom da smanje gubitke i povećaju učinkovitost u mreži.

Najčešće ne postoji dovoljno provedenih nadzora kako bi se točno odredio uzrok ovih gubitaka što otežava prepoznavanje preopterećenih transformatora, nezakonitih priključenja i pogrešaka u mjerenju koje ugrožavaju pouzdanost mreže, sigurnost ljudi i financijske rezultate.

U ovom članku se opisuje tehnološki pristup kojim se omogućuje bolja percepcija pogonskog stanja mreže, temeljen na stvarnim mjerenjima i analitičkom predviđanju.

Prikupljanjem i analizom određenih podataka o mreži poboljšava se sposobnost predviđanja preopterećenja i ispada. Trenutni podaci iz mreže smanjuju financijski rizik kombinirajući konvencionalnu naplatu i podatke pametnih mjerenja o trenutnoj potrošnji u mreži te na taj način točno određuju mjesto krađe kao i pogreške u mjerenju/naplati.

Ključne riječi: smanjenje gubitaka, analiza mreže, predviđanje, uštede

A NOVEL APPROACH TO LOSS MITIGATION USING GRID ANALYTICS AND ENERGY/LOAD BALANCE SURVEYS

SUMMARY

Utilities are faced with more than $200B in annual losses and theft, which are steadily increasing by 2.5% per year, yet are under pressure to reduce losses and increase efficiency across the grid.

There is rarely enough monitoring in place to pinpoint the cause of these losses making it difficult to find overloaded transformers, illegal bypasses and metering errors that compromise grid reliability, public safety, and financial performance.

This paper describes a technology-based approach to provide situational awareness of grid operating conditions based on actual line measurements and predictive analytics to provide insight into the operating condition of the distribution grid.

Bringing visibility to an otherwise invisible network improves the ability to predict overloads and avoid outages. Actual line data reduces financial risk by truing up conventional billing and smart meter data to the actual consumption on the lines, pinpointing theft as well as metering/billing errors.

Key words: loss mitigation, grid analytics, prediction, savings

1. INTRODUCTION

1.1 In-Grid Data – pinpointing problems in the grid

With enough money and resources, it is conceivable to monitor every piece of every distribution line and every transformer and every other asset in the distribution network with no gaps. If such a moonshot project were ever funded, and there were enough data handling and analytics capacity to understand this **in-grid data**, it would then be possible to determine the cause of every problem and identify every opportunity for optimizing grid operations.

No utility has the financial resources, however, to deploy such a gapless wide area monitoring system in the low voltage and medium voltage network. There are an estimated 1.5 million km of MV and LV distribution lines in Europe alone [1]. Many utilities have instead deployed systems on the edges, with: a) substation monitoring with intelligent devices, and b) automated meter reading and smart meter systems. In both cases, part of the goal is to extrapolate and model the distribution grid using only what can be measured from the power flowing into and out of the grid segment.

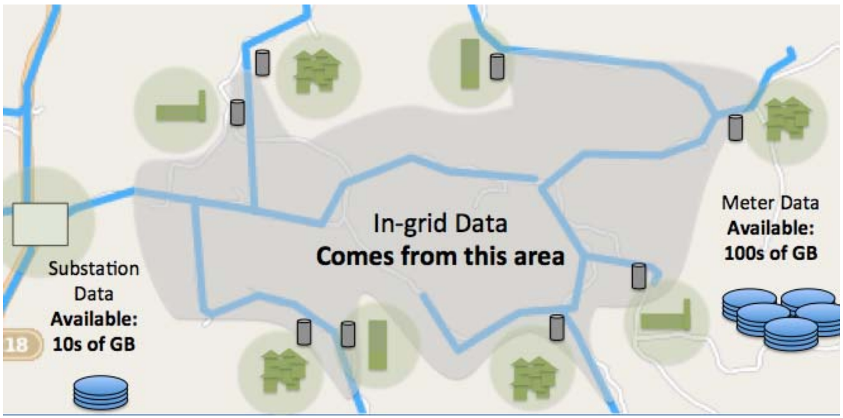

Figure 1. Simple grid segment showing in-grid data

Sadly, the promise of deep knowledge of grid operations through substation devices at the core and billing meters at the edge of the grid has not been met. Power flow models can only predict flows based on known loads. Consumption profiles may be aggregated to estimate load factors for transformers but phase mis-association, unmetered loads and diversions and other operational deficiencies can make these models inaccurate at best and misleading at worst. Sources of essential in-grid data remain elusive.

2. PREDICTING PROBLEM AREAS

Surprisingly, when a monitoring or metering project is funded, there is a common assumption that all substations or all consumers should be treated more or less equally and furnished with approximately the same level of technology. This one-size-fits-all approach overlooks a key consideration: losses and other problems in the grid are not uniformly spread throughout the network. This fact allows us to approach the task from another angle.

Take the example of smart meter rollouts, which are often cited as a key part of the battle to reduce theft and reduce losses. Smart meter deployments are extremely capital-intensive projects. The EU has called for 80% of citizens to be equipped with smart meters by 2020, which amounts to 200 million smart meters [2].

Conventional wisdom leads to deployment of smart meters for the largest consumers first. If the goal is to reduce theft, however, experience shows that theft is more common among residential consumers, medium-sized businesses, and rural consumers where there is less visibility of illegal connections.

Any optimization task can benefit from recognizing that some areas in the grid are more likely to have problems than other area. Some variation of the Pareto principle is a reasonable assumption: that utilities can expect to find 80% of the problems in 20% of the grid. Alternatively, the greatest potential for optimization may be within just 20% of the grid.

3. TECHNICAL AND NON-TECHNICAL LOSSES

Technical losses are observed throughout the distribution grid and are generally unavoidable, since they are primarily caused by resistive losses on conductors, and both copper losses and core losses in the transformers. Non-technical losses are the result of a wide range of causes, including: unmetered loads (e.g. streetlights), intentional or inadvertent meter bypass, illegal and undocumented connections, meter tampering, and errors in metering or billing. Sometimes these losses are also called “commercial losses”.

In any distribution network there will be few grid segments with very low technical losses, and few grid segments with exceptionally high technical losses. The normal probability distribution function is a reasonable model for the likelihood of finding technical losses in the grid.

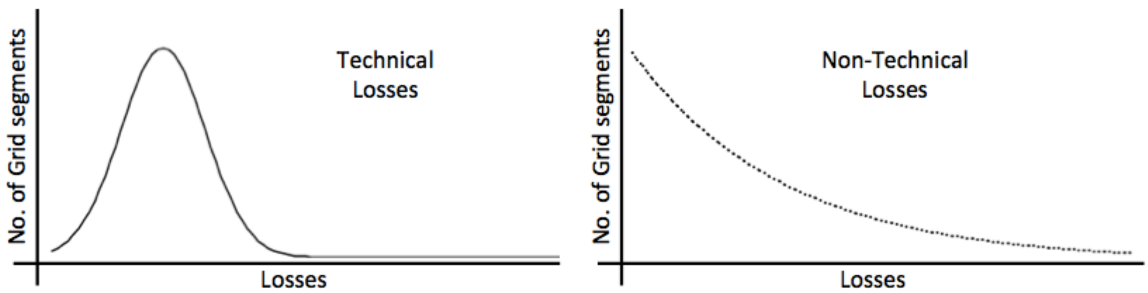

Figure 2. Probability of technical and non-technical losses

The probability of finding non-technical losses, on the other hand, may be modeled using an inverse distribution. This is because most grid segments will have very low non-technical losses, and a decreasing number of grid segments will have higher losses – up to 100% loss in severe cases.

Overall losses may be modeled with the convolution of the two probability distribution functions, which shows that the majority of the grid segments with higher losses will be due to non-technical losses. The challenge is one of identifying the segments with the highest combined losses.

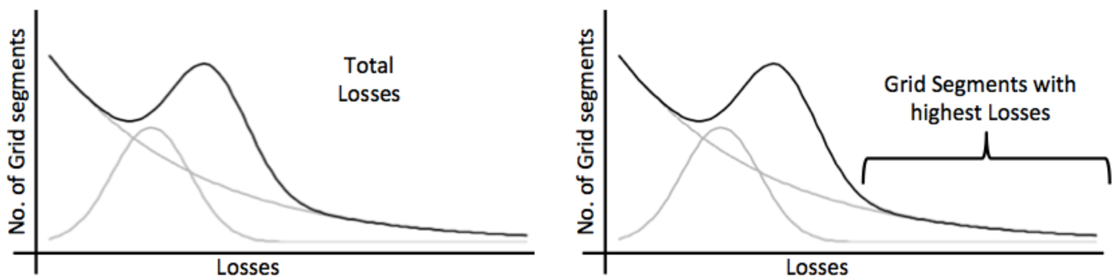

Figure 3. Probability of total losses and highest losses

4. GRID SEGMENTATION

Predicting problem areas can be approached in two stages: defining grid segments, and then developing a risk model that is applied to the grid segments. In designing a methodology to find high-risk grid segments, it is important that the grid segments are defined in a predictable and repeatable manner. A grid segment may be treated as a small grid management area. Some of the possible attributes that can be used to define grid segments:

- Can the segment be traversed in a normal working day if a field investigation is necessary?
- Can the number of customers of each type and tariff be assessed within a normal working day?
- Can aggregate loads and consumption be estimated and verified?
- Are the conductors accessible for sensor placements if needed?
- Can the segment be divided into sub-segments if needed?
- Can the risk model and risk metrics be applied on the segment?
- Is the segment size appropriate for measuring the expected level of losses?

Defining grid segments is a non-trivial matter that can be refined as the optimization program unfolds, and can be adjusted to the business objectives. Suitable grid segmentation leads to better utilization of field investigators'time and associated resources.

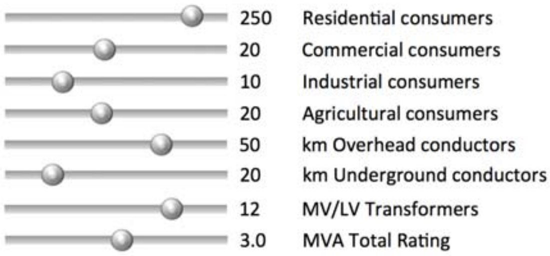

Figure 4. Some possible parameters used to define grid segments

5. RISK MODELING

Having defined the grid segments, the next step is to define a risk model. Risk modelling has its roots in the finance industry, where investment and insurance companies have developed sophisticated methodologies to evaluate key risk indicators, apply specific assumptions, and use the resulting model to drive strategic decision making.

In the context of electricity distribution, applying a risk model to sell-defined grid segments leads to the risk-based ranking of the segments. This ranking determines the corresponding priority of in-grid data analysis.

The risk model can use various existing data sources, for example:

- Billing data, and billing data analytics (e.g. average annual revenues, trends)
- Metering data, and metering data analytics (e.g. load profile anomalies, alarms)
- Customer data, and customer data analytics (e.g. payment history, disconnects, complaints)
- Load factor data and trends (i.e. actual consumption relative to circuit capacity)
- Grid segment monitoring data and trends (i.e. line metering or transformer metering data)

For each grid segment, the risk Rs is assessed as follows:

$$R_s = \sum (I_{rf} \bullet \times W_{rf}) \qquad (1)$$

where Irf is the impact of a risk metric, and Wrf is the weight. The weighting of the risk metric may be a simple threshold or multiplicative factor, or it may be a complex formula:

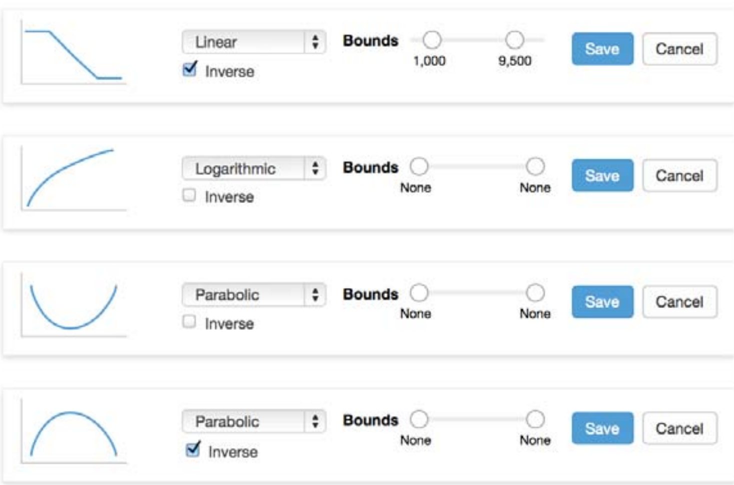

Figure 5. Risk factor weighting formulas

Flexibility in applying weights to risk metrics is an important part of honing the model to a utility. Local expertise and on-the-ground knowledge gives insight into the true grid operating conditions, and elevates the risk model from the generic to the specific.

When the risk metrics have been selected, as well as the impact and weighting factors, we can apply the risk model to the grid segments and create a ranked list of grid segments.

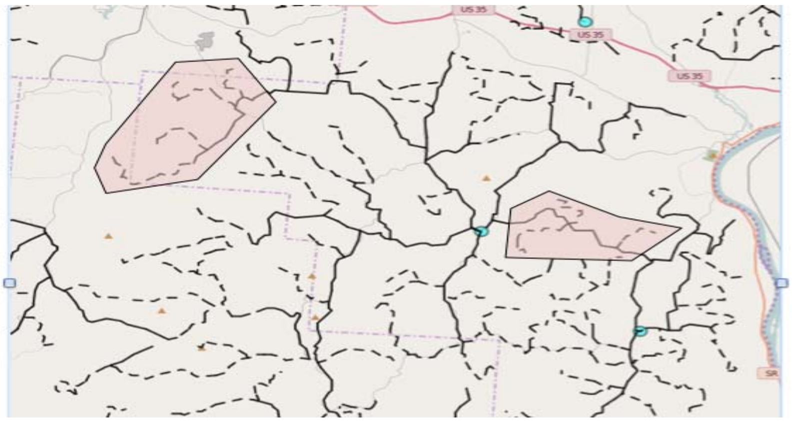

Figure 6. Visualizing grid segments targeted for optimization

An important consideration is that the risk ranking may be applied multiple times, first at a high level to rank the grid segments, then at a narrower level to rank sub-segments. The risk model may also be adjusted as the data sources are refined. Furthermore, by feeding the results of field investigations back into the risk model, we set the basis for machine learning.

6. CASE MANAGEMENT

6.1. Triage

For each of the identified high-risk grid segments, the case manager must decide if further investigation is justified. In the world of risk and case management this is often referred to as *triage* where the priority is determine by assessing the severity of the problem.

Some distribution grid segments can be triaged because of individual knowledge or policy decisions. A more structured approach to triage may be based on a cost benefit analysis (CBA), in which the expected benefit of fixing the problem is assessed relative to the cost of doing so. Some simple examples:

- Is it worthwhile to pursue electricity theft on a residence, if the cost of reducing the loss is twice the annualized value of the loss?
- If the losses in a target grid segment are high, but the location is very remote and the cost to travel to the area is higher than the value of the losses, should it be ignored?
- Should a transformer be upgraded if the cost of the newly installed transformer will be recovered through efficiency improvements within 5 years?

Note that CBA can be expressed in terms not strictly monetary. For example, in cases where consumers (or a whole consumer category) might be identified as economically disadvantaged, utilities can approach the problem as a social issue and recognize their losses as a subsidy. Even in this case, the losses may still need to be found and quantified.

For a more complex CBA, the analysis may also consider reliability, stability, and corporate policies. CBA will often include the net present value (NPV) of the benefit over the life of the fix. As a result of triage, some high-risk grid segments may simply be tagged as having known losses and/or set aside for future assessment.

6.2. In-Grid data

For the targeted grid segments worthy of investigation, we use case management and field investigation tools to collect & validate necessary in-data. The following multi-stage approach applies:

Planning:
- Select a target grid segment
- Review and incorporate previous investigation results, if any
- Validate grid topology, incorporate latest grid topology changes
- Prepare investigation plan, propose sensor placement, validate and adjust
- Review/confirm access to metering data, billing data grid assets as required

Field data collection
- Deploy sensors and record metering data
- Note topology changes and other field anomalies
- Validate and associate sensor data, metering data, billing data

Reporting
- Generate energy balance report(s), phase balance report(s), transformer load report(s), etc.
- Identify cause of loss & quantify loss
- Run additional reports as required (Phase Association, GIS data discrepancy, etc.)
- Update KPIs and dashboard with results

6.3. Documentation

Serious causes of loss may trigger an internal audit or a legal challenge by a consumer.

For this reason it is essential that at each stage of the field data collection and reporting we anticipate the need to justify the steps taken, and to prove that the data and results are accurate and complete.

All steps and all results must be documented and placed in a secure repository for future reference. Furthermore, it is important to demonstrate that the investigation was an evidence-based undertaking, untarnished by discriminatory practices. With detailed data showing actual line conditions time-stamped at the time of collection, we can supply sound, unbiased evidence in cases that may take months or years to litigate.

7. IN-GRID ANALYTICS

Significant value derives from an in-depth analysis of the results of the field investigations as the cases are processed. Unlike conventional meter data analytics, it is often possible to predict similarities between grid segments based on findings, and to predict grid performance in other grid segments with similar characteristics.

A simple example of the in-grid analytics approach compared to meter data analytics alone might serve to illustrate the advantage of this approach.

7.1. In-Grid Sensor data analytics vs Smart Meter data analytics

In this scenario, assume all four homes are consuming approximately the same amount of energy: say 2 kW average (48kWh per day) and are being supplied by a 25kVA transformer T.

The load on transformer T should be approximately 8kW. If the bypass losses B1 and B2 are each 10kW loads – which is not unusual for marijuana grow operations, for example – then the total load on transformer T increases to 28kW.

Using smart meters and meter data analytics, the voltage drop caused by the excess load on house 2 meter will register as a low voltage outlier, because the illegal tap B1 is on the line supplying the house. All of the smart meters will register the same voltage drop caused by illegal tap B2 and it will remain undetected. The aggregate load on the transformer T will be estimated as 18kW, which is still within the rating of the transformer.

Using in-grid data analytics based on data from sensors S1 and S2, the actual load conditions can be determined (28kW) and the risk of an overloaded transformer will be registered.

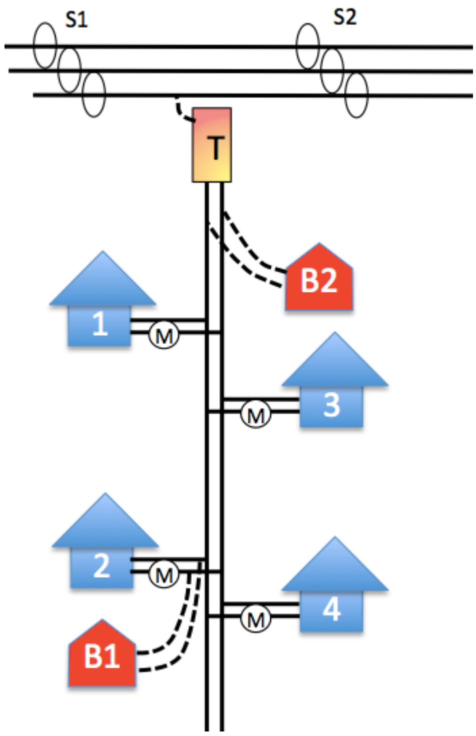

Figure 7. Illustrating limitations of meter data analytics

The example shown in figure 7 is just one scenario where smart meter analytics alone can fail to identify loss and the resulting risk to grid assets. Many other problems relating to grid efficiency can be determined using in-grid analytics based on in-grid sensor data.

Furthermore, as the in-grid data is collected during the course of case management and field investigations, a data model of the distribution grid can be built. This provides a virtual grid monitoring system that forms the basis of a wide range of additional analyses.

Vendors of big data analytics solutions aimed at the utility industry rely heavily on meter data analytics (with perhaps some transformer monitoring data) to estimate, extrapolate or calculate the actual grid operating conditions. Despite being capable of integrating weather data, consumer data, and numerous other inputs, one key element is hidden from them all – in-grid data – that exposes actual grid operating information.

8. CONCLUSIONS

Risk-based assessment of the electricity distribution grid is a cost effective alternative to the massive investment required to implement continuous wide area monitoring. By focusing analytics and resulting field investigations on the segments of the grid that are most likely to have severe loss problems, the utility can gain a good picture of the problem areas using a cost effective and scalable approach.

Furthermore, the need to address these losses continues to grow. Many utilities struggle to recover revenue from unavoidable losses, while regulators are limiting the practice of passing the cost of losses onto the consumer. The most immediate source of increased revenues for many utilities come from within their distribution grids.

Developing a risk model also allows the revenue protection group to align with an over-arching corporate enterprise risk strategy. Most large utilities have risk management processes, and it is often the office of the Chief Financial Officer (CFO) or the Chief Risk Officer (CRO) that is tasked with overall strategic risk management and governance. Enriching their insight with a risk-based assessment of avoidable losses can improve the entire risk management framework.

True grid intelligence provides the foundation of situational awareness of grid operating conditions based on actual line measurements and in-grid analytics. The methodology described can be used to find overloaded or unbalanced transformers, illegal bypasses and connections, metering errors and other problems that compromise grid reliability, public safety, efficiency and the financial performance of the enterprise.

9. LITERATURE

[1] http://www.harriswilliams.com/sites/default/files/industry_reports/final%20TD.pdf

[2] http://www.eurelectric.org/media/113155/dso_report-web_final-2013-030-0764-01-e.pdf