A SENSITIVITY STUDY OF THE SWEDISH NETWORK PERFORMANCE ASSESSMENT MODEL INVESTIGATING EFFECTS OF CHANGES IN INPUT DATA

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ABSTRACT

This paper present results from a sensitivity study of the Network Performance Assessment Model (NPAM) as an effect of changes in input data. The NPAM estimates a cost corresponding to operate a fictive reference network, so called network performance assessment (NPA). This value is then compared with the revenue. Small changes have been implemented at the customer data level for real electrical distribution systems e.g. moving a low-voltage customer a few meters. Results show on that the NPA could differ up to 7 million Euros. The main conclusion is that a small divergence in input data could result in significant differences in the output data from the NPAM.

INTRODUCTION

A regulatory tool, named *the Network Performance Assessment Model* (NPAM) [1] has been developed in Sweden to support the regulation of electrical distribution system tariffs [2]. The NPAM was a paradigm shift for the Swedish Distribution System Operators (DSO). From a regulation model based on compensation for costs to one based on the performance they give their customers, i.e. *customer value*. The NPAM is based on *reference networks*; fictive electrical distribution systems defined from a set of conditions, such as location of customers and delivered electrical energy. This information is annually reported by every DSO to the regulating authority. The model performs a *network performance assessment* (NPA), expressed as norm costs to operate the *reference network*, and compare this value with the revenue, which give a debiting rate:

$$Debiting\ rate = \frac{Revenue}{NPA}$$

Equation 1 – Output used by the regulating authority

A review of the tariffs, utilizing the NPAM, is performed yearly by the regulating authority since 2003. By virtue of the model, several DSOs have been ordered to return a part of the revenue, if the debiting rate is higher than an acceptance level. The decisions of repayment have been contested by the DSOs, resulting in an ongoing legal process. Indications of too large sensitivity in the NPAM have been claimed, which have motivated further studies of this phenomenon.

THEORY

This paper presents results from studies made by the authors investigating the robustness of the NPAM [3] [4]. The results included in this paper are selected results from a sensitivity analysis of the NPAM investigating the effect of changes in input data. A complete presentation of this sensitivity study is presented in [3].

The Network Performance Assessment Model

Theoretical studies of the NPAM have shown that the algorithm that creates the *reference networks* contribute to the possible sensitivity presented in [3]. The economic value of this *reference network* determines a significant part of the total NPA. The NPAM creates a *reference network*, independent of the real structure of the electrical distribution system. The algorithm begins at low voltage, divides the customers into clusters, creating fictive radial networks with a transformer for each cluster [5]. The fictive transformers are always located at the same coordinates as an existing customer. The fictive transformer data are then input used when the algorithm continue to create the next voltage level. A small change of input data can therefore lead to chain reactions on all voltage levels. After the construction of a fictive radial network, compensation for redundancy is added from template functions, which depends on the *subscriber density* of the fictive radial network [6]. The NPA and other output data from the NPAM are calculated with the software *Netben* [5].

Voltage levels in the NPAM

The *reference network* of the NPAM has maximum four voltage levels, called *Net Levels* [1]. The amount of *Net Levels* depends on the highest *Net Level* where the electrical distribution system is connected and supplied by superior grids in *border feed points* [1]. The real nodes of the electrical distribution system are divided up in *Net Levels* as follow in the fictive *reference network*:

- *Net Level 1* (NL1) – 0.4 kV, where all nodes (e.g. customers) below 1.0 kV are located.
- *Net Level 2* (NL2) – 10 kV, where all nodes between 1.1 and 25.0 kV are located.
- *Net Level 3* (NL3) – 40 kV, where all nodes between 25.1 and 60.0 kV are located.
- *Net Level 4* (NL4) – 135 kV, where all nodes above 60 kV are located.

If two customers have different voltage levels in the real electrical distribution system, they can still receive the same *Net Level* in the fictive *reference network*, i.e. it is not unusual with both an 11 kV- and a 22 kV-level in the same electrical distribution system, which both situated at NL2.

APPROACH

This paper shows on phenomenon which can appear with a small change in the input data. The first step was to study the algorithms of the NPAM. Then create a test system, both to control that the algorithms behave as expected and to identify small changes that have relative high effect on the results of the NPAM. This, together with discussions with a DSO (Fortum Distribution), gives a list of relevant changes to study; first on the test system, then on real electrical distribution systems.

The study is divided into five parts. The first four involves different approaches to sensitivity in customer input data. These are tested and applied to real electrical distribution systems. The fifth step involves further investigations and analyzes of the NPAM. Results [3] presented in this paper are given in terms of the calculated NPA from the NPAM. The Swedish currency SEK is translated to Euros by using the rate: 9 SEK = 1 Euro. Figure 1 - Figure 4 display output data from *Netben* showing the structure of the highest *Net Level* of actual *reference network* and transformer stations (in the software it is possible to choose what to be illustrated). Broken lines are connections to superior grids trough defined *border feed points*.

APPLICATION STUDIES

Part 1 – one customer is moved

The regulation authority accepts the accuracy of 30 meters for the coordinates of the low-voltage customers (0.4 kV) [1]. In this application study, one low-voltage customer is moved 2, 3 and 18 meters respectively, i.e. changes within the accepted accuracy. Real data from the electrical distribution system of the Swedish town "Karlskoga" have been used. This electrical distribution system has approximately 16 000 customers and the NPAM gives a value of NPA of 9.2 million Euros per year before any changes. The customer, with changed input data, has an annual consumption of electricity of 188 900 kWh.

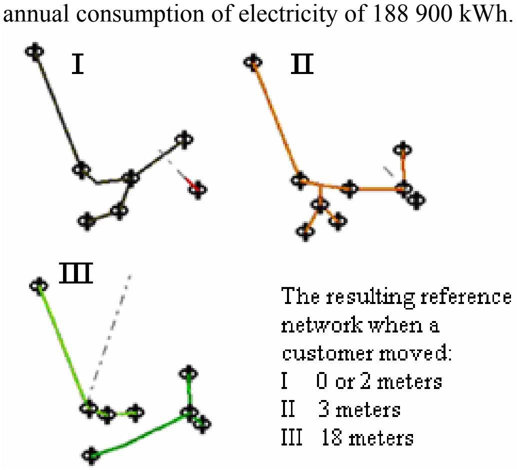

Figure 1 – Different resulting reference networks when the location is changed for one customer in Karlskoga.

Figure 1 shows three resulting *reference networks* at NL3 created by the algorithms of the NPAM. If the customer, in the "Karlskoga application study", is moved two meters, the overall structure of the *reference network* does not change at all. The NPA (see Equation 1) is changed less than 10 Euros. When same customers reference point is moved three meters in the same direction, a new structure of the *reference network* appears. The NPA is now increasing with approximately 50 000 Euros. A third structure appears after 18 meters and the NPA becomes approximately 65 000 Euros higher, comparing with the original case. The two changes of structure are shown in Figure 1 together with the original structure.

The customer coordinate data does not always have an exact accuracy in real electrical distribution systems. This is known and accepted by the regulating authority *Energimarknadsinspektinen*. Neither the expenses for the DSO nor the *customer value* should be radically dependant on the exact location of one customer. Therefore, the results from part 1, indicates on the possibility of unmotivated sensitivity in the NPAM.

Part 2 – consumption changed for one customer

In this application study, one of the low voltage customer receive an increase of annual consumption to 34 365 kWh and 34 370 kWh respective (original value is 19 375 kWh). Real data from the electrical distribution system "Västkusten", including parts of the south west of Sweden is used. Västkusten has more than 110 000 customers and the NPAM gives a value of NPA of 46.4 million Euros before any changes.

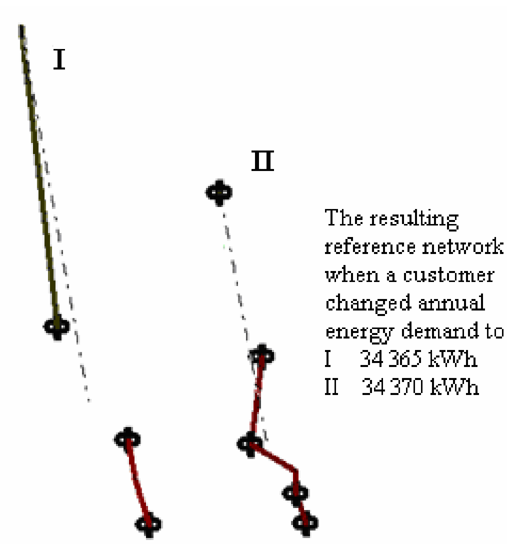

Figure 2 –Two different resulting reference networks when the energy demand was changed in Västkusten.

When the consumption was increased to 34 365 kWh, neither the structure of the *reference network* (left part of Figure 2) or the NPA received significant changes. When the consumption instead was changed to 34 370 kWh, the structure at the NL4 was radically changed (right part of Figure 2). The difference in NPA between 34 365 kWh and 34 370 kWh is approximately 408 000 Euros. It is notable that the NPA decreases when the consumption increases.

The results, including part 1, show that relative small changes, in different kind of input data can give an unmotivated divergence in output data. In additional to this, part 2 shows that higher power demand in the electrical distribution system can decrease the NPA and a relatively small change in NL1 can change the structure of all *Net Levels* in the *reference network*.

Part 3 – one new customer

In this application study, a new customer, with an annual consumption of 1000 kWh/year is added to the electrical distribution system. Real data from the electrical distribution system of the Swedish province "Värmland" is used. This system has more than 320 000 customers and the NPAM gives a NPA-value of 145 million Euros before any changes. Three different examples are presented here, when the NPA decrease as a consequence of the new customer (location 1 in Figure 3), when the NPA is approximately unchanged (location 2 in Figure 3) and when the NPA increase (location 3 in Figure 3).

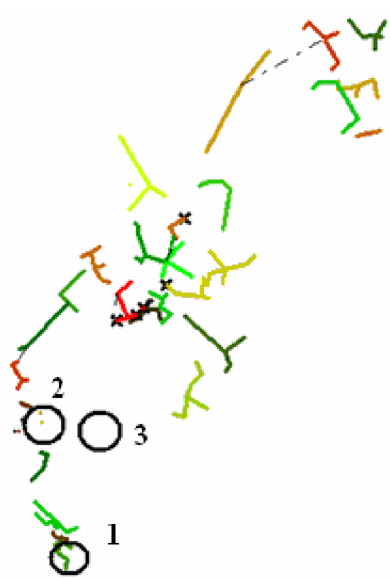

Figure 3 – Three different locations for a new customer in Värmland illustrated at the reference network.

Figure 3 shows NL4 of the *reference network* before any changes and indicates the alternative locations for the new customer.

Table 1 – Change depending of location

Location	The resulting change of NPA	
1	- 328 000 Euros	-0,23 %
2	0 Euros	0,00 %
3	+ 6 814 000 Euros	+ 4,7 %

The DSOs have an *obligation to serve*, i.e. are forced to connect new customers to the electrical distribution system. The conclusion from part 3 is that a new customer can give a lower or a higher NPA, and the change of NPA can be several millions of Euros. The indirect consequence of a changed NPA is changed allowed total revenue for the DSO.

Part 4 – changed voltage level for one customer

In this application study, one customer is located at a higher voltage level (NL3 instead of NL2) in the *reference network*. The same electrical distribution system as in part 2 is used. An increased *Net Level* for one customer results in a decreased NPA with 3.8 million Euros (- 8.1 %).

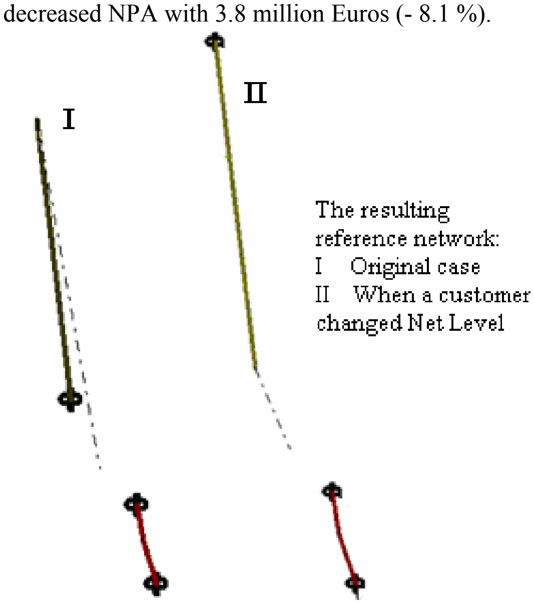

Figure 4 – The reference network before and after the change of Net Level for one customer in Västkusten.

The large change in the NPA depends on the connection between the *reference network* and a *border feed point* (broken line in Figure 4), i.e. the connection to the superior grid. This result shows that the resulting *Net Level* of one or few customer is important for the results of the NPAM. This is interesting; because the *Net Levels* of the NPAM do not always coincide with the voltage levels of the real electrical distribution system. This will be analyzed in future work.

Part 5 – further analyzes

Other aspects of the NPAM, in addition to the sensitivity as an effect of changed customer data, were investigated in [3]. Three of these analyses are selected to be published here.

a) The possibility of unrealistic reference networks

This application study theoretically investigates if the algorithms of the NPAM can create unrealistic components in the fictive *reference network*. The fictive transformers are always located at the same place as an existing customer [1]. It is, for example, not realistic to locate a high voltage transformer station (e.g. 135 kV) in a residential district. Furthermore, the NPAM does not take the real terrain into consideration [1], which can lead to strange line building, e.g. over mountains or lakes. The conclusion is that the *reference network* can include structures and nodes, which is outside the norm for real electrical distribution systems.

b) A border feed point become a customer

This application study is a sensitivity analysis of the algorithm to connect *border feed points* with the *reference network*. A *border feed point* supply the system with energy and has a negative value of annual consumption [kWh]. If a *border feed point* consume more than it "give", this value become positive. This is realistic, e.g. a reserve connection with no supply during the actual year, but with some own consumption. In these cases the algorithm of creating *reference network* treats the *border feed point* as an ordinary customer. The algorithm always connect all customers (even if the consumption is zero), but only a *border feed point* if it is considered to be needed for the energy balance [5]. The consequence can be that a DSO get paid for the connection with the *border feed point* if it has an annual consumption of "1 kWh", but not "-1 kWh".

Same electrical distribution system as in part 2 and 4 was used to test if this can lead to any consequences. A new *border feed point* was added. If the supply was low or zero, the output data of the NPAM was unchanged. The new *border feed point* was not connected. If the annual consumption instead was set to 1 kWh, the output data was changed. The NPA was increase approximately with 4.25 million Euros. Together with the results in part 4, this give an indication that the algorithm to connect *border feed points* can cause sensitivity in the NPAM.

c) Sensitivity analyze of supply points

This application study is a sensitivity analysis of the algorithm to connect *supply points*, e.g. normally small hydroelectric power stations, with the *reference network*. The NPA become the same (if costs and revenues are unchanged) regardless of the delivered energy (extreme values was also tested) in the supply point. The conclusion is that the connection of these does not affect the overall structure of the *reference network*.

CONCLUSIONS

Results from a sensitivity study of the Swedish regulation method have been published in this paper. The main conclusion is that a small realistic divergence in the input data could result in significant differences in the output data from the NPAM. A small change of input data at low-voltage can change the whole *reference network*. Changes which should give more expenses for the DSO, e.g. higher power demand or an additional customer can result in lower NPA, which indirect leads to lower revenue allowed. The changes of NPA, depending on one small change of input data could differ up to 7 million Euros.

DISCUSSION

The examples in this paper shows on some extraordinary sensitivity in the NPAM. However, it is important to realize that these examples are not extreme values. Moreover, experience from the work with the NPAM indicates that several divergences neither tend to interact nor to cancel each other.

FUTURE WORK

The results published in this paper show possible consequences of sensitivity in the NPAM. It would be interesting to study these phenomena more systematic, e.g. the probability distributions, how different parts of the NPA behave and correlations. These types of studies are included in ongoing work [4] by the authors and results will be published during 2007.

Acknowledgment

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