NEW PLANNING METHOD FOR SMART AND ACTIVE DISTRIBUTION GRIDS

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ABSTRACT

In order to handle the increased uncertainty in future electric power generation and demand, probabilistic models should be used to model the risk when choosing among the different planning alternatives. If probabilistic data are available for the decision variables (e.g. historic observations), then the uncertainties can be described by suitable probability density functions. If probabilistic data are not available, then the planner can instead use her/his experience and knowledge to construct possible scenarios and their associated probabilities. Network calculations can be performed by specific probabilistic load flow algorithms or a more general Monte Carlo simulation approach. The results of these calculations are the stochastic representation of the nodal voltage and branch current variables, through which the technical constraints can be verified with a relative confidence (acceptable risk of violation).

INTRODUCTION

Planning of distribution grids in Norway has so far generally been relatively simple and predictable. Consumers have been passive and their consumption has followed almost the same pattern year after year. There has been almost no distributed generation (DG) connected to the distribution grid.

The need for increased transfer capacity has been met by grid reinforcement and the dimensioning has been based on a worst-case scenario and a fit-and-forget approach. Consequences of this reinforcement practice might be poor utilization of the grid capacity and consequently high costs. These high costs might be a barrier for the development of new DG-projects.

In the future distribution grid, things will be more complex and unpredictable:

- Consumers become more active (Demand Response, DR)
- Active load control by others than the customers (Demand Side Management, DSM)
- A larger number of unregulated DG connected to the grid
- Energy efficient but power intensive equipment
- Electric vehicles (EVs) are new loads
- Smart grid technologies (monitoring and control, automatic operation, self-healing grid, etc.)

Is there a need for a new planning methodology or is today's methodology good enough for the future's smart and active distribution grids?

In this paper there is a focus on modelling of loads for use in power system planning. A small low voltage distribution grid with one distribution transformer and three equal domestic consumers connected will be used as an example in this paper, see Figure 1.

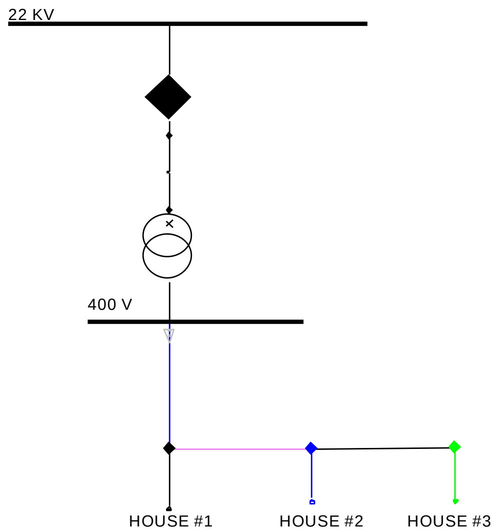

Figure 1 Small LV grid used as an example

TODAY'S DETERMINISTIC METHOD

Many utilities in Norway use the power system planning approach described in [1]. The methodology is shown in Figure 2.

The quality of information about loads and production is essential for the technical analysis of alternatives. Differences between estimated (calculated) and real load flow might lead to over- or underinvestment in the grid.

For most of the electric energy consumers today, only information about consumer category (household, office building, industry, agriculture, etc.) and annual electric energy consumption is available. Standard load profiles and prognoses for the different consumer categories are used. When calculations are performed on the MV grid, the LV network is usually not included because of the complexity and the size of the load flow model. Instead, the LV network is represented as one single load connected to the low voltage side of the distribution transformer. The same standard load profile and prognosis are used for all these loads.

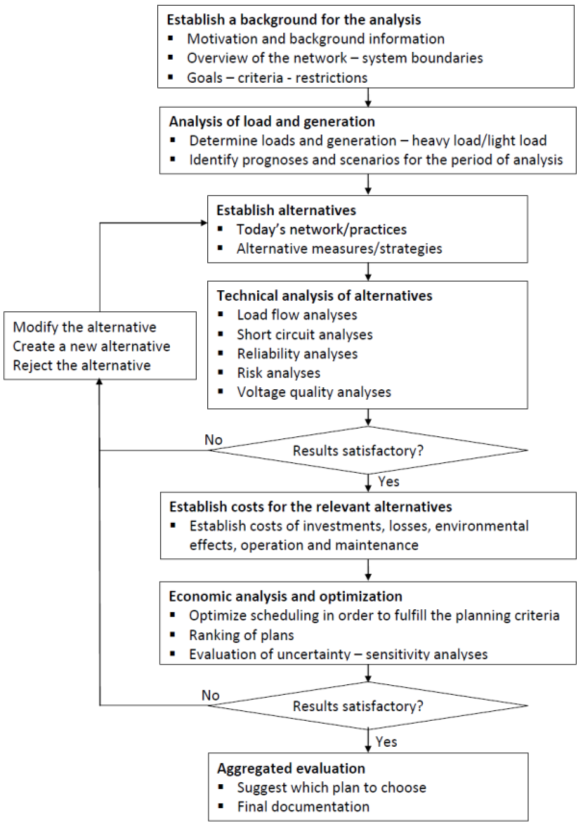

Figure 2 Distribution system planning methodology [1]

For generators the generation is registered on an hourly basis, but for purpose of power system planning either maximum or zero generation is used. According to the present Norwegian regulation, the grid operator cannot put restrictions on the level of production for a generator connected to the grid.

AMR-DATA AS INPUT TO PLANNING

In Norway all customers should have smart meters by January 1st 2019 [2]. With these new meters a lot of valuable information for use in power system planning can be obtained:

- Hourly/quarterly load metering
- Voltage quality registration (voltage level, hourly average, maximum and minimum)
- Load interruptions. Registration of interrupted power and duration
- Fault localization information

Smart meters and flexible tariffs will also promote flexible loads, demand response (DR), demand side management (DSM), dispatchable loads, aggregators and smart homes.

Extended use of sensors and automation (e.g. smart distribution substations) will provide valuable information that can be used in power system planning:

- Improved condition monitoring and state estimation
- Improved/optimal operation. Automation.
- Faster fault localization and fault correction. Self-healing grid.

Calculation of load variation curves

Collect and arrange data

Metered kWh/h-values for each consumer can be collected from the Meter Data Management System (MDMS). These values must be allocated to date, hour of the day, day of week and month. Public holidays can be considered as Sundays.

Temperature correction

Since a large part of the Norwegian energy use is related to heating, a part of the energy use is dependent on the temperature. The temperature varies from year to year, and in order to use values from several years, the kWh/h-values must be temperature corrected to the same reference – e.g. an average year.

Temperature data can be obtained from different databases. In Norway data from different climate measuring stations can be downloaded from http://eklima.met.no. Data for the station closest to the planning area should be used:

- Three-day-average (or daily average) measured temperature each day
- Normal daily mean temperature for each day (average for the last 20-30 years)

Temperature corrected kWh/h values can be calculated by using equation 1:

$$\boldsymbol{P_{corr\,i} = P_i + P_i \cdot k \cdot x \cdot (T_i - T_n)]} \quad \textbf{(1)}$$

Where

- $P_{corr\ i}$ = Temp. corrected kWh/h-value hour "*i*"
- P_i = Measured energy use hour "*i*" (kWh/h)
- k = temperature dependent part of the energy use (in %)
- x = describing the temperature sensitivity of the temperature dependent part of P_i (° C^{-1})
- T_i = average for the last three days (3-day average) of measured temperature, day "i"
- T_n = Normal daily mean temperature for the specific day

The factors k and x in Eq (1) will vary from load to load.

Temperature correction should not be done for the summer months June, July and August.

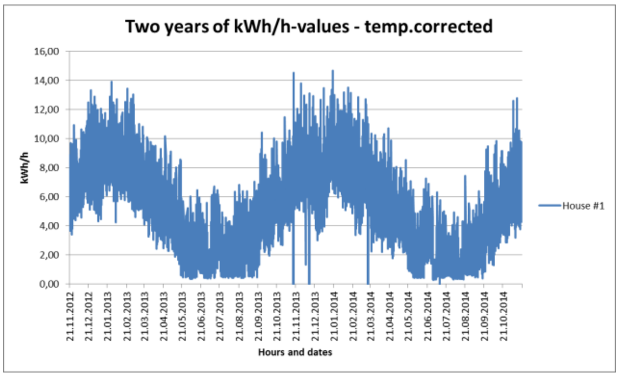

Figure 3 Metered load in kWh/h over two years at House #1

Figure 3 shows metered load in kWh/h over two years for a domestic home in Norway.

Variation curves – expected values

Many of the distribution utilities in Norway use the system NetBas for power system planning and grid analyses. Until now loads have been represented by their maximum load, a yearly prognosis (yearly increase in %) and variation curves for year (months) and day (hours). Standard prognoses and variation curves are used for different consumer categories. With AMR, variation curves and prognoses can be estimated for each consumer.

Today different variation curves are calculated for year, day of week and hour of the day. The weekly and daily variations are assumed to be relatively the same every month. This is not necessary true. By using metered kWh/h-values it is possible to calculate one variation curve for each combination of month, day of week and hour of the day. This variation curve will consist of 12x7x24 = 2016 values and take into account that the weekly and daily variation respectively can be different in January and June.

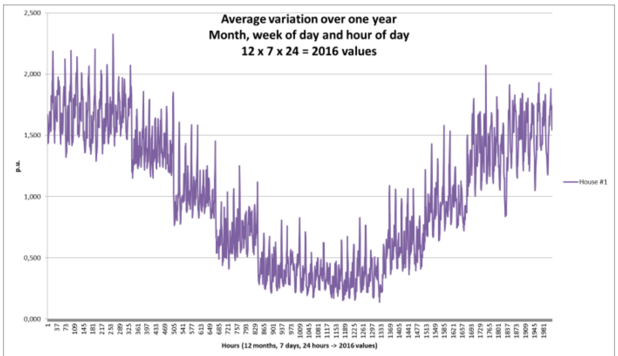

Figure 4 Average variation over a year, House #1

Figure 4 shows an example of an average variation curve over a year for one domestic consumer. The variation is based on kWh/h-values for a period of two years[1].

Deviation between metered and expected load

The deviation between the metered values and the expected value due to the average variation curve for House#1 is shown in Figure 5 and Figure 6. The average value of the random deviation in Figure 5 is zero.

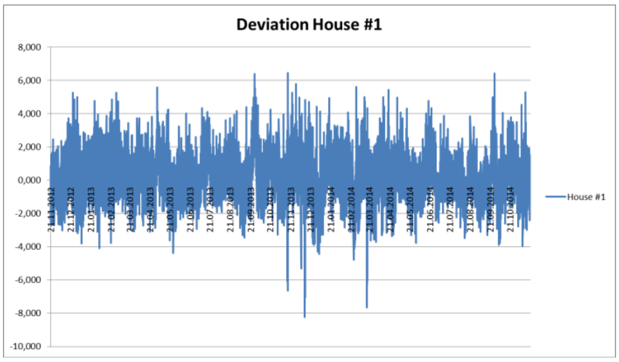

Figure 5 Deviation between metered and expected load, House#1, two years

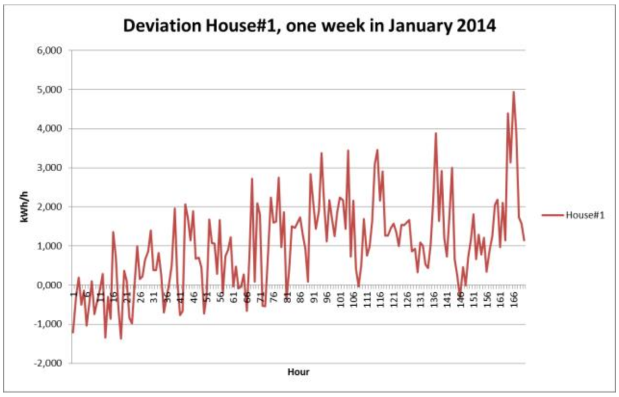

Figure 6 Deviation between metered and expected load, House#1, one week in January 2014

Deviation as a statistical distribution function

The deviation in Figure 5 can be expressed by a statistical distribution function. By using statistical methods it is possible to estimate this function. In this particular case the Burr distribution fits the sample data deviation best. In Figure 7 the deviation in kWh/h is along the x-axis and the distribution fit is along the y-axis.

1 It should be based on metered values for several years (5-10), but time-series that long are not available today.

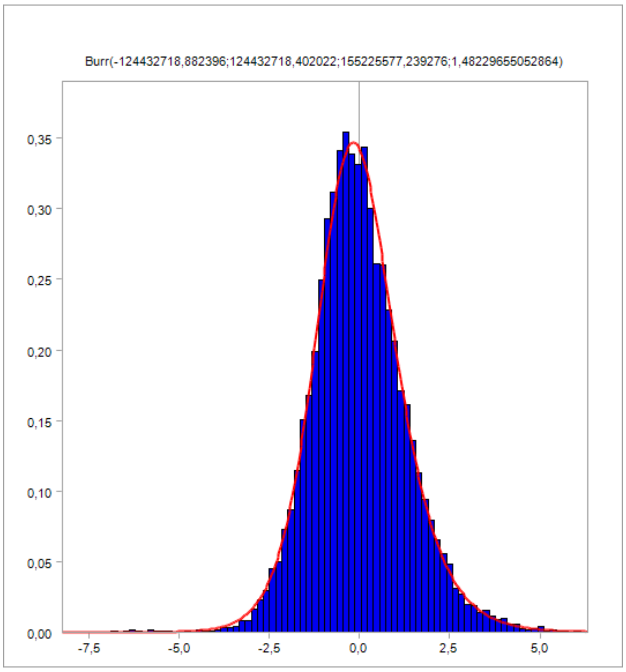

Figure 7 Random load deviation distribution (Burr distribution)

Load model

The load can now be modelled as an expected average load according to a variation curve like the one in Figure 4 and a statistic distribution function describing the statistical deviation from this average value.

If this is done for every load in the grid, similar load models can be aggregated for parts of the grid like:

- Low voltage grid connected to one distribution transformer.
- Medium voltage grid connected to one transformer substation.
- The whole grid operated by one distribution utility.

EXAMPLE - LOAD FLOW CALCULATIONS

Load flow calculation programmes must be able to handle load models like the one described above. For the example shown in Figure 1, Microsoft Excel is used for the load flow calculation. An Excel spreadsheet for simple load flow calculations downloaded from [1] is used in this example. For risk modeling and MonteCarlo simulations the Excel ad-in ModelRisk[2] is used.

When loads are modeled by using average expected load and a distribution function describing the statistical deviation from the average, it is also possible to calculate expected values and distributions for currents, loads, losses etc. in the grid.

2 Vose Software BVBA ©

The three loads in Figure 1 are modeled as equal loads with the same expected load (10 kW) and the load deviation distribution shown in Figure 7. The distances between the 400 V busbar, House #1, House #2 and House #3 are respectively 100, 200 and 300 meters. The cable used in the example type is TFXP 4x25 AL.

Traditionally calculation method gives the results in Table 1.

Table 1 Results from traditionally load flow calculations

Total load	30.00 kW
Losses	1.79 kW
Max current	47 A
Lowest voltage	367.3 V

A traditional load flow calculation says nothing about the variations and probability for one particular load. Load flow calculations done with Monte Carlo simulations give almost the same expected values in Table 2 as the results from traditional calculation in Table 1.

Table 2 Results from load flow calculations with Monte Carlo simulations and distribution functions – expected values

Total load	29.92 kW
Losses	1.77 kW
Max current	46.63 A
Lowest voltage	367.3 V

The Monte Carlo simulations give additional information about variations and probabilities in the calculated load flow. Examples of results are shown in Figure 8, Figure 9, Figure 11 and

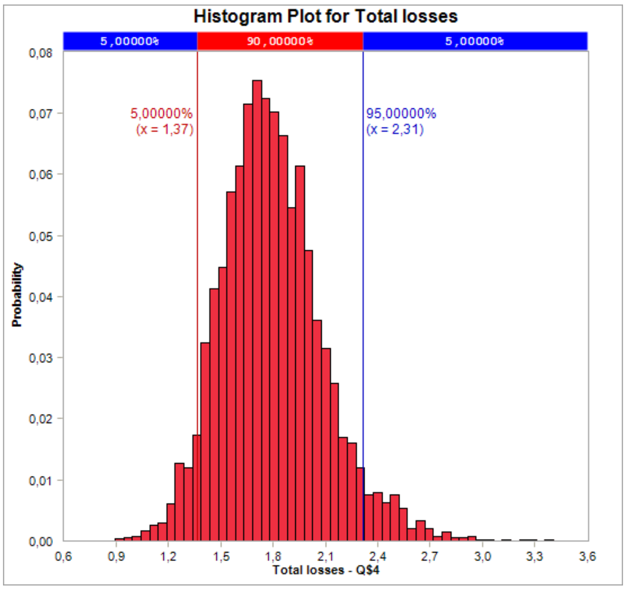

Figure 8 Histogram plot for total losses

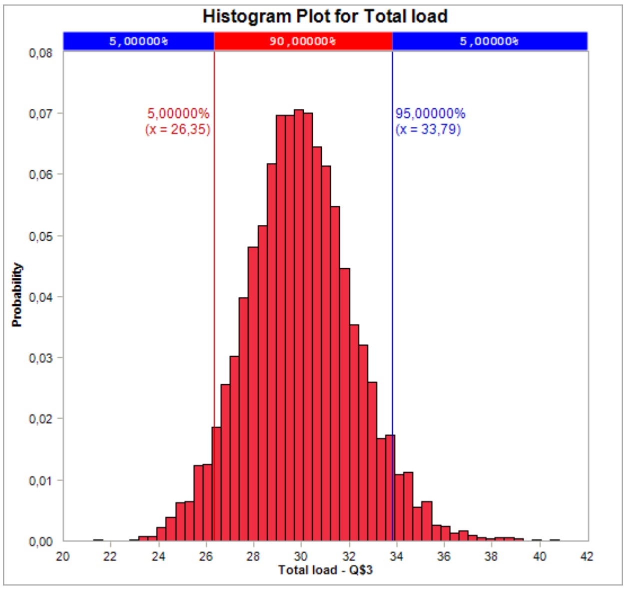

Figure 9 Histogram plot for total load

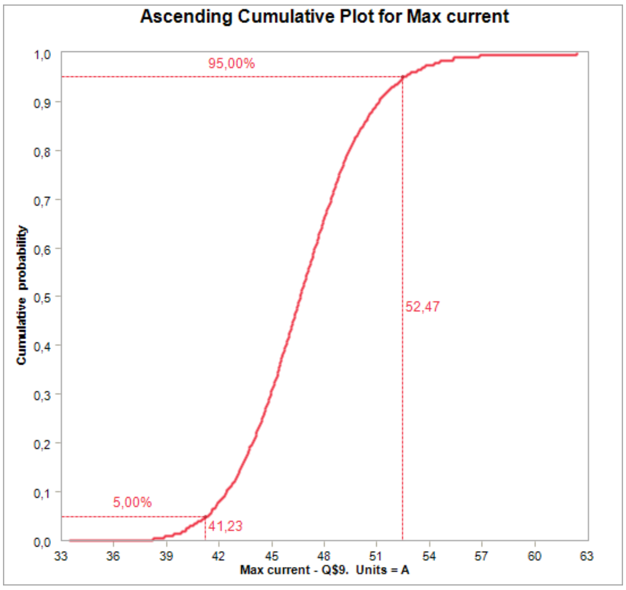

Figure 11 Cumulative plot for maximum current

Statistics	
Variable	
Name	Max current
Sim #	1
Units	A
# of Samples	5000
# of Errors	0
# Filtered	0
Location	
Mean	46,70657196
Minimum	33,42376011
Maximum	62,39219495
Spread	
St. dev.	3,438310888
Variance	11,82198176
CofV	0,07361514116
Shape	
Skewness	0,2298453081
Kurtosis	3,463782331
Percentiles	
1%	38,87300796
5%	41,22814494
15%	43,23726634
25%	44,44034019
35%	45,38159213
45%	46,21087384
50%	46,6291794
65%	47,90090147
75%	48,83713809
85%	50,15212586
95%	52,47333008
99%	55,38810428
Max current	

Figure 10 Statistics for maximum current

CONCLUDING REMARKS

It is shown that it is possible to calculate a new load-model based on hourly/quarterly energy metering. A load model that consist of an expected variation curve over the year and a statistical distribution function that describes the normal deviation from this expected variation curve.

Load flow calculations performed with the use of Monte Carlo simulations give information about expected values and probability distributions around these expected values.

Expected values have been used for both calculation methods in the example in this paper. Traditional load flow calculations are historically done deterministic using extreme values. This means that the total load should have been approximately 40 kW instead of 30 kW. Then the maximum current would have been approximately 60 A and the total losses about 3.3 kW.

Increased uncertainty and variations in future electric power generation and demand should be analysed with probabilistic models in load flow calculations and power system planning. Traditional deterministic models will lead to overinvestment in grid capacity.

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[1] "Planleggingsbok for kraftnett," ed. www.planbok.no: Sintef Energy, 2012.

[2] *Regulations on metering, billing and coordinated action in power sales and billing of network services*, www.lovdata.no FOR 1999-03-11-301, 1999.