A PROBABILISTIC APPROACH TO POWER FLOW ANALYSIS

Zbyněk BRETTSCHNEIDER
PREdistribuce, a.s. - Czech Republic
zbynek.brettschneider@pre.cz

Radek HANUŠ
PREdistribuce, a.s. - Czech Republic
radek.hanus@pre.cz

Zdeněk MÜLLER
CTU in Prague - Czech Republic
mullezd1@fel.cvut.cz

ABSTRACT

This paper shows some opportunities offered by new approaches to processing planning and distribution network management data. The increasing amount of phenomena that are difficult to predict (e.g. decentralized sources, electromobility etc.) decreases the informative value of currently used calculation methods. These methods also require accurate input data. Using methods from the probability theory allows us to describe the reality more accurately in the conditions with increased amounts of uncertainty.

INTRODUCTION

Calculating the distribution network operation has become so mastered that it can be considered a routine. The current technology provides sufficient calculation performance, which virtually does not limit us in the extent of the network being calculated while keeping the response time short. It is also common to use calculation software, which contains many calculation algorithms. The software is able to adapt the algorithms depending on the situation in order to achieve the requested calculation accuracy. All these above described successes apply only on one condition. The accurate input data like the parameters of single components in a distribution network and, first of all, the volume of input and output performance into and out of the particular system must be correctly inserted. Considering the new trends in Power Engineering, this assumption is gradually less and less realistic.

PROBLEM DESCRIPTION

Network operation calculations are commonly processed for the busiest state of operation, which is usually the so called winter maximum (summer minimum), when the network load is maximal (minimal). By checking the resulting parameters we then find out whether the distribution network complies with the required standards. From this comparison we draw the conclusion for potential service and development measures. It is automatically assumed that the distribution network parameters are more convenient at other times than the winter maximum (summer minimum). Thus, it is not necessary to analyze these states any further. The new trends in Power Engineering obviously lead to the decreasing information value of the existing algorithms for calculating networks and they will probably create the need to change the current approach.

We include especially minor decentralized production among the above mentioned trends (e.g. rooftop photovoltaic systems, cogeneration and wind power plants) and consumption with significant fluctuation (electromobility in particular).

The problem of calculating the network operation lies on two levels. Firstly, the behavior of decentralized production and electric cars is more difficult to predict because it is influenced by more factors than what is usual for conventional power sources and consumption. From the perspective of the distribution network development plans, the fundamental problem occurs when, as a rule of thumb, we do not know whether the particular consumer will equip their consumption point with e.g. a photovoltaic supply unit or whether they will own an electric car. And if we assume these for that particular person, will we also assume them for their neighbor? A wide range of various scenarios arise. The problem includes also the moment in time that will have an impact on the distribution system.

For us this represents the moment we need to dimension the electric facility. Will the moment be in winter (as we have been used to up to now) or rather in summer, when the cogeneration still produces and the photovoltaic units can reach the rated performance? Will there be more and more uncertainty? It seems necessary to examine the wider range of all alternatives. This puts enormous requirements on the network calculators, who have to input and process all alternatives, evaluate them and from the single calculations then set the resulting limit states.

SUGGESTING A SOLUTION

A possible solution of this complicated situation can be realized by changing the approach to calculating the distribution network operation. In these conditions it may prove to be more beneficial to substitute the current unambiguous inserted supply and consumption data with a probabilistic description of behavior.

For the sake of calculating the network operation we do not describe the consumer's behavior in the network node with a particular supply/consumption value. We use a probability density supply/consumption load *f(I)*. The probability density function graph ranges from negative to positive values, which makes it possible to describe the supply and consumption behavior in the particular node. The limits are given by the consumer's main circuit breaker (or by the fuses).

The supply/consumption probability density function graph takes 2 main aspects into account:

A. The randomness of a particular consumer in time – it determines the individual influence probability density.
B. The probability of applying a particular influence in the particular network node – it determines the weight of influence on the resulting probability density of the particular node behavior

The following figure shows an example of how the particular influences apply.

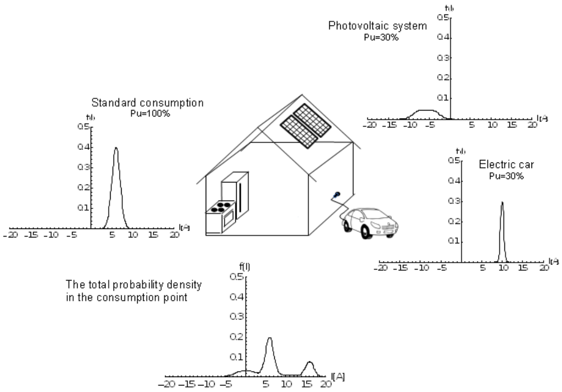

Figure 1: The particular influences in the supply/consumption probability at a particular consumption point

As an example of a consumption point we are using a family house. In this consumption point we distinguish 3 types of supply/consumption diagrams:

- Standard consumption
- Supply from the roof photovoltaic unit
- Electric car consumption

Each of these diagrams is described by the supply/consumption probability density in time. Generally speaking, it is a 3D graph with one axis representing the supply/consumption *load(I)*, the other axis is the particular supply/consumption probability density *f(I)* and the third axis represents the time *t* (for a 0 – 24 hours daily diagram). If we look into the system for one moment in time (we make a time incision), the single influence behavior will be depicted as a 2D graph.

The probability density is described as a function. Our calculations work especially with normal distribution. In general it is possible to work with any function or distribution. If we know the value of input data with a large degree of certainty, the corresponding distribution variance will be low and the probability density function will be "peaked". In the case of large uncertainty regarding the input data, the variance, as well as the density function, remains "flat".

The consumption/supply load usually changes throughout the day and so does the probability density function variance.

The resulting probability density function in a particular node is given by the weighted addition of the potential influence probability density – the usual load, photovoltaic units, cogeneration, electric cars etc. This function results from convoluting the functions of the single influences. In the process we have to consider the application probability of each influence.

$$Y = I_1 + I_2$$

$$f_Y(y) = \int_{-\infty}^{+\infty} f_{I_1}(y - I_2).\, f_{I_2}(I_2)\, dI_2 \qquad (1)$$

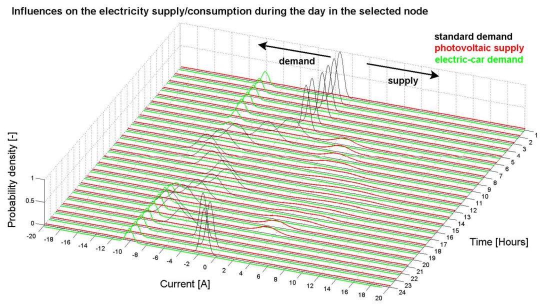

Figure 2: An example of applying the single influences in a particular node throughout the day

As stated above, the algorithm calculation input are not the specific consumption/supply values. For this purpose we use the probabilistic consumer behavior in the particular distribution network node.

The actual network operation calculation procedure is based on the resulting probability densities of a particular node behavior. The single steps are carried out using probability density convolution on the single distribution network branches. The calculation outcome is then particularly the load probability density of the power supply transformer and the voltage load probability density in the single network nodes. After processing these outcomes we can determine the degree of probability concerning the current and voltage limits.

If we know the single node behavior, we can calculate the current flow in the single distribution network branches using the Probability Load Flow (PLF). The outcome does not show the unambiguous current or performance values. However, we obtain the probability density *f(I)* or *f(P)*.

The following picture shows a visual example of a low voltage distribution line with three consumption points. Using the PLF we can obtain probability density of the power supply transformer load. Based on the determined probability density we can calculate the single node voltage load probability density.

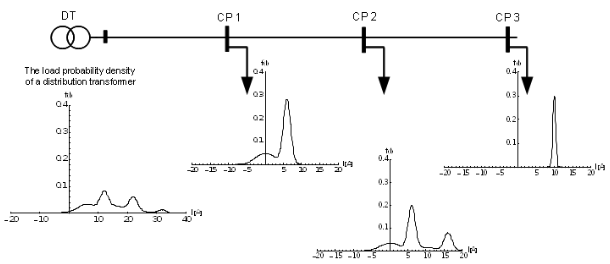

Figure 3: Example of low voltage distribution line with three consumption points – Ti time incision

It is possible to apply the Probability Load Flow to a multi-node network.

The network operation is based on the following universally valid equations:

$$P_i = U_i \sum_{j=1}^{n} U_j \left(G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}\right) = f(\delta_1,\ \delta_2,\ \dots \delta_n,\ U_1,\ U_2,\ \dots\ U_n) \quad (2)$$

$$Q_i = U_i \sum_{j=1}^{n} U_j \left(G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}\right) = g(\delta_1,\ \delta_2,\ \dots \delta_n,\ U_1,\ U_2,\ \dots\ U_n) \quad (3)$$

In order to simplify the process of solving the PLF, we will use a network operation simplified calculation (DC load flow) with using amplitudes of phasors:

$$|\boldsymbol{I}| = [|\boldsymbol{Y}|]|\boldsymbol{U}| \ \rightarrow \ \ |\boldsymbol{U}|' = [|\boldsymbol{Y}|']^{-1}|\boldsymbol{I}|' \quad (4)$$

$$|\boldsymbol{I}_{ij}| = \frac{|\boldsymbol{U}_i| - |\boldsymbol{U}_j|}{|\boldsymbol{Z}_{ij}|} \quad (5)$$

The dependency can be efficiently solved using convolution.

Figure 4 shows an example of a low voltage distribution line with a graphical representation of the probability calculation using the DC Load Flow.

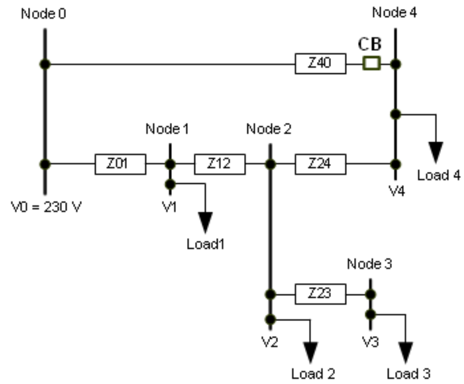

Figure 4: Example of 5-nodes low voltage grid

The given network is, depending on the switching element, operated either as a radial one or in a loop.

Figure 5 represents the PLF outcomes – the decrease in single nodes for radial operation as well as loop operation of the system.

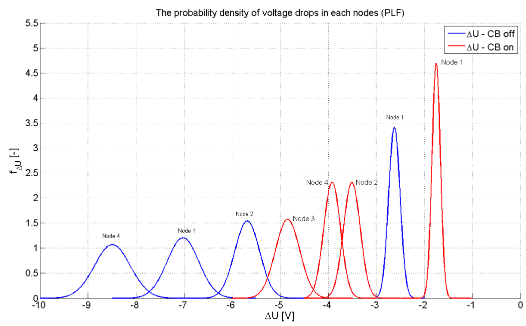

Figure 5: The probability density of voltage drops in low voltage grid for the state of Circuit Breaker (CB) – on (network structure - loop) or off (network structure - branch)

We can also achieve the probability flow method results by using the Monte Carlo method. It randomly matches consumption/supply to the particular nodes in the system and calculates the system operation for each of those matches. By evaluating a significant set of the calculations we are able to approximate the single value behavior probability density that we obtain from the PLF. For achieving the appropriate explanatory power for the Monte Carlo method it is necessary to execute virtually tens of thousands of independent system operation calculations.

Figure 6 shows the PLF and Monte Carlo method outcome in comparison. For obtaining the Monte Carlo method outcome we made 20000 independent system operation calculations.

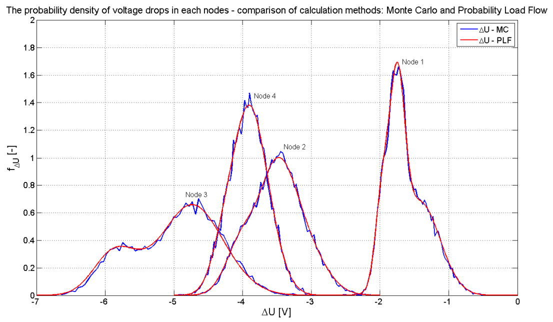

Figure 6: The probability density of voltage drops in low voltage grid for the state of CB - on. The comparison of calculation methods: Monte Carlo (MC) and Probability Load Flow (PLF)

The single variable probability density function makes it possible to determine the so called probability of exceeding operation risk limits – it determines how probable it is that the existing current limit of a particular branch will be exceeded and how probable it is that the distribution network voltage limit values will be exceeded.

It is convenient to use the probability degree of exceeding the limits in the particular distribution network branches or nodes as the input data in the distribution network development and operation.

While the deterministic approach to network operation gives information only about the system behavior at a particular moment and provided that the input values are known, the probability approach to network operation calculation can help us determine the most convenient state of the distribution network even under non-deterministic assumptions if we have the probability input for calculation.

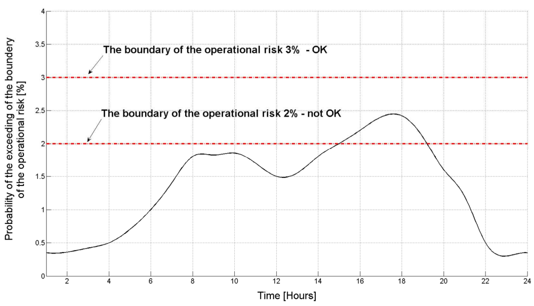

Figure 7: The probability process of exceeding the operation risk limits

The process of calculation is shown in the following diagram.

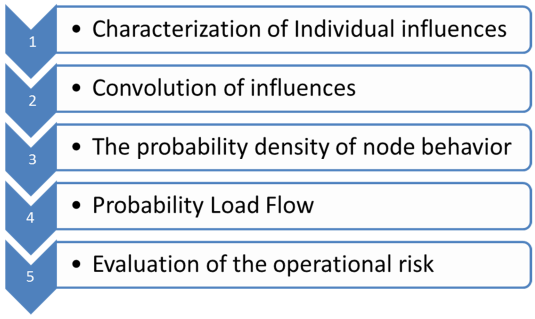

Figure 8: The calculation algorithm

1. The individual influence description – The aim is to determine the consumption/supply probability density of the particular influence in a given node.
2. Influence convolution – Processes the individual influences mathematically. It is possible to solve them analytically as well as numerically. We recommend the numerical processing for multi-node systems (n>5).
3. The probability density of node behavior – Determines the resulting course of consumption/supply probability density in the node.
4. Probability Load Flow (PLF) – The calculation uses the probability density input of the single nodes.
5. Evaluating the operation risk – The evaluation is carried out from the probability viewpoint and it also considers the voltage limit exceedance in the single distribution network branch.

CONCLUSION

The increasing uncertainty on the side of the distribution system calculation input, which is caused especially by decentralized sources and electric cars, lead to the decreasing information power of the current calculation methods. This unfavorable situation can be solved by changing the approach to the distribution network operation calculations. By shifting to the probabilistic approach we can achieve a higher quality level and increase the information power of network operation calculations.

REFERENCES

[1] Barbara Borkowska, 1973, "Probabilistic Load Flow", *IEEE PES Summer Meeting & EHV/UHV Conference*, pp. 752-759

[2] Rifki Terzioglu, T. Fedai Cavus, 2013, "Probabilistic Load Flow Analysis of the 9 Bus WSCC System", *International Journal of Scientific and Research Publications*, vol. 3, issue 9, pp. 1-4

[3] Johannes Schwippe, Olav Krause, Christian Rehtanz, 2011, "Extension of a Probabilistic Load Flow Calculation for the consideration of Interdependencies", *Proceedings 17th Power Systems Computation Conference*

[4] Zechun Hu, Xifan Wang, 2006, "A Probabilistic Load Flow Method Considering Branch Outages", *IEEE Trans. Power Syst.*, vol. 21, no. 2, pp. 507-514