PLANNING OF PROJECTED MEDIUM-VOLTAGE POWER GRIDS A TOOL THAT MEETS THE REQUIREMENTS OF TODAY'S REGULATED MARKET

Atalay PUHAVA
RWE Rhein Ruhr Netzservice GmbH - Germany
atalay.puhava@rwe.com

Thomas NIEMAND
RWE Energy AG - Germany
thomas.niemand@rwe.com

1. ABSTRACT

Over the last twenty or thirty years, developments in power-supply grids have always involved systematic planning of grid expansion. Despite this, medium-voltage power grids have developed over a long period of time and these now show redundancies at many points. The current basic conditions in the regulated market are now forcing network operators to significantly reduce the operating costs of power grids. Criteria such as quality and reliability of supply are thereby increasing in importance. Furthermore, as equipment which outlasts its initially expected economic life is not taken into account when calculating grid usage charges, a significant trend for renewing these power grids will be established in the coming years.
This article on the planning and optimisation of a grid presents a tool, which enables grids to be converted into optimal structures and to configure them in line with the changed demands. The method presented here is based on a solid, consistent database containing geo-referenced data on the grid and technical aspects. This data is then entered into a simulation software module. Grid plans which can be used for calculation, detailed knowledge of load flows on the grid and the consideration of relevant reliability criteria often enable results that can be utilised rapidly. Even with no grid construction it is possible to minimise power losses by, for instance, optimising disconnection points of medium voltage feeders. The systematic approach and main economical results are shown using a real project.

2. INTRODUCTION

During the 1960s and 1970s, power grids were intensively expanded due to strong economic growth. This has now led to a situation, where the power grid infrastructure is rather inhomogeneous. Moreover, much of the equipment has now reached the end of its life from a technical and economic point of view and is becoming increasingly prone to failure. Against a background of security of supply and age structure, power supply grids must be renewed systematically. Power grids were constructed in the past with corresponding reserves because of the rates of load increase at the time. Today, there is no expectation of any large increase in load, even in the longer term, and so it is generally uneconomic to replace equipment on a 1:1 basis when renewing power grids. If one also takes into account the peak loads that occur now and those that are anticipated in the future, then projected power grids can be designed with significant potential for dismantling.

3. GENERAL NOTES ON PLANNING A PROJECTED POWER GRID

A projected power grid describes a future power grid that is optimised in accordance with technical and economic criteria taking into account all the factors influencing it. The role of a power-grid planner is to gather and order logically the large body of information including technical data, customer data, official guidelines etc. This enables the medium- and long-term development of the power grid to be estimated realistically. The objective of the planning process is to design the power grid as economically as possible, whilst adhering to the essential conditions, e.g. voltage stability, reliability of supply and ability to withstand short circuits.
In the process of replanning power grids, which have grown over a lengthy period of time and different parts of which are of very different ages, it is not possible to apply a green-field approach without taking into account the existing equipment. The green-field approach is chosen for creating reference power grids. With the help of mathematical calculations, automatically generated power grids are created. These theoretical reference power grids effectively serve as a benchmark. It is thus possible to investigate which projected power grid comes closest to the reference power grid in terms of operating and investment costs, power losses and reliability of supply. The reference model, which can also help with finding a practical solution, is not discussed in greater detail in this article.

4. OPTIMISING MEDIUM-VOLTAGE POWER GRIDS

4.1 Analysing current power grid status

Nearly all planning offices now use power-grid simulation programs. Depending on the development status of the power supply companies, interfaces are put in place between graphic information systems (GIS) and network information systems (NIS) for the purpose of interfacing with the grid simulation software. A purely diagrammatic power grid plan which can be used for calculation can be created without geo-data, using spatial data from the equipment and the load values for the stations.
Actual power-grid analysis and the planning based on it can only be carried out in a geographical plan. When analysing the existing power grid it is important to understand fully how the power grid operates. Experience has shown that a medium-voltage overview plan showing the switching states in colour is an ideal aid to this depth of understanding. It

clarifies the load flow, its direction and the way in which the power grid works. By taking into account the load data, age structure and critical components, usable and not usable components, bottlenecks in the grid and peak loads are identified.
To increase transparency and to analyse the power grid systematically it is helpful to divide it into logical geographical sections.

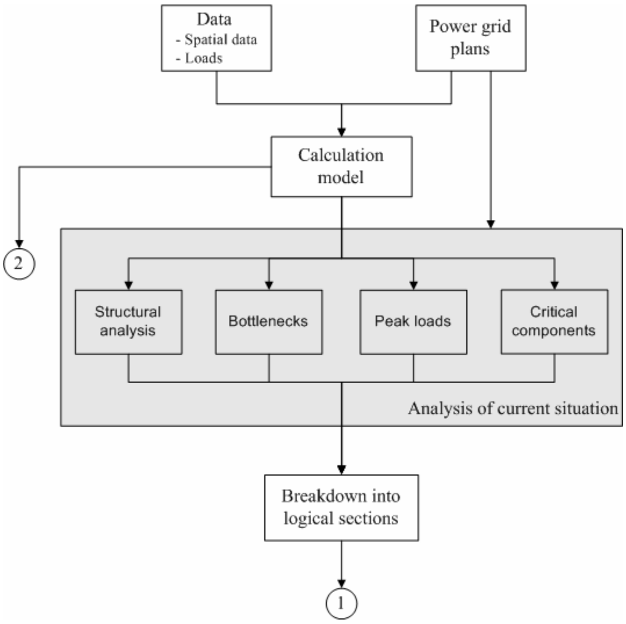

Figure 1: Analysing current power grid status

4.2 Optimising the power grid

Step 1: Establish premisses
The first step in planning any projected power grid is to define the premisses present in the current power grid.

- Are there any substantial triggers for replanning a power grid?
  - Increases in power due to new areas
  - Increase in power due to individual large customers
  - Addition of non-central power feed ins, e.g., designating land for new wind farms
  - Particular requirements for security of supply

- What should be the primary objective?
  - Cabling of old overhead lines in rural power grids
  - Reduction of assets (substations and lines)
  - Reduction of outgoing circuits in 110/10 kV station

Step 2: Optimise disconnects
The optimisation of disconnection points based on power losses is the simplest and quickest way of optimising power grids and saving direct costs (direct cost reduction by kWh). Where there is a calculation model, the optimisation of disconnects can be carried out even before the analysis and replanning of the power grid. The following criteria can apply additionally:

- Security of supply
- Avoiding power grid reactions
- Corporate interests (access, deployment times)

Step 3: Replan the power grid
When carrying out fundamental replanning of an existing power grid, the planning engineer needs to proceed with a great degree of creativity. Far-reaching structure-altering measures can have the effect of optimising the condition of the power grid in respect of the established premisses. The accompanying power grid calculations ensure that the required reliability criteria, e.g., the n-1 principle, are complied with.
The projected power grid should be characterised by simple structures with rings and lanes. Cross connections should be used only sparingly to resolve bottle-necks and postpone capital investment. In geographically-contained sections of a power grid, package substations should be avoided since they involve not only high initial investment but also high, ongoing operating costs.

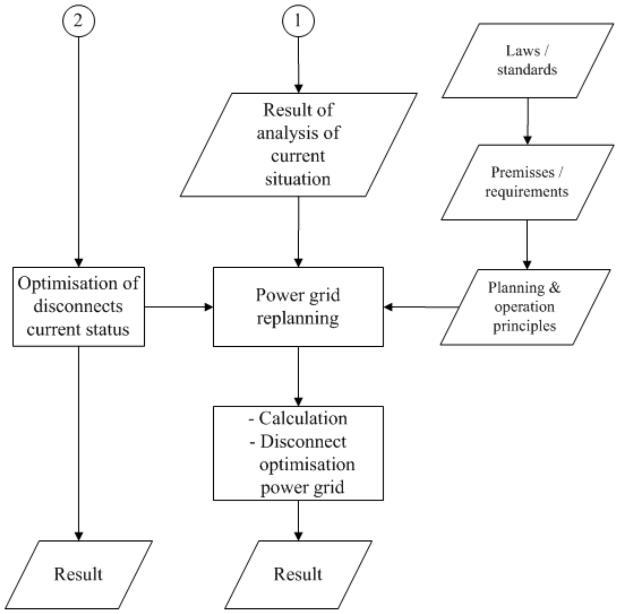

Figure 2: Optimising the power grid

An important criterion when replanning a power grid is systematic consideration of the average loading of all the cable outlets in a station. In conjunction with the geographical reference it becomes clear how many cables with what degree of load are supplying part of a region. If the loading on the cables is very low (e.g., < 30%) and if only a small number of stations are supplied by each primary feed cable, this serves as an indication that there is plenty of potential for optimisation. Decisions on which equipment and systems should be decommissioned, which to a certain extent can already be made simply by altering the cabling, takes into account the age and available information on critical components. If the planning of a projected power grid is carried out under the premiss that increased power is needed, then supply cables that are becoming free can be used for this purpose without the need for laying extra long feed cables.

Step 4: Complete the power grid calculation
Finally, a comprehensive calculation run is performed on the replanned power grid. The calculation of load flow and short circuit current confirm the way in which the power grid has been optimised in its normal condition and also the reliability criterion has been satisfied when there is a fault. In conclusion, a new optimisation of disconnects is carried out to enable the power losses to be optimised in the projected power grid as well.

5. PLANNING A PROJECTED POWER GRID USING AN URBAN GRID AS A MODEL

The chosen reference grid is an urban medium-voltage cabled power grid with an overall length of 160 km. The grid is supplied from two independent 110/10 kV stations and its maximum load currently stands at 30 MVA. Since one of the two stations is located outside the city boundaries there is high-performance 4x300 mm2 Cu connection to a transfer station. In a centrally-located commercial area there is another package substation, which is likewise linked via 300 mm2 Cu cable to the transfer station and the second 110/10 kV station. The medium-voltage power grid is configured as a mixed grid comprising rings, lines and numerous cross-connections. There are 250 substations connected to the medium-voltage grid.

5.1 Analysing current power grid status

5.1.1 Producing a calculation model

The grid operator did not have a closed system of spatial data. In the course of a service job, tables were made available in electronic form; these provided an overview of field notebooks and station data with cable outlets. Important items of technical spatial data such as types, cross sections and ages of cables and lines can be found in the field notebook overview. The maximum loading values for the power-grid stations and customer stations, which were measured using trailing pointer instruments, were made available for the analysis. There were also series of measurements and thus load curves for the 110/10 kV station and the transfer station.

5.1.2 Geo-referenced overview plan

By adding Gausz-Krüger coordinates to the station database and with the aid of the power-grid plans provided (paper version) it was possible to generate a geo-referenced 10 kV overview plan semi-automatically. To increase the transparency of the planning task posed, the switching state of the power grid was produced in colour.

5.1.3 Breakdown of power grid into logical subnetwork sections, and initial analysis

The calculations of load flow and short circuit current for the existing power grid show that there are no bottle-necks at present and that the average load on the cables is only around 30%. As it is best to supply power via short cables with sufficiently large cross sections, voltage stability doesn't present any problems either. The short circuit capacity of the power grid is measured in the two stations that are supplying power as 250 or 150 MVA.
At the outset of the analysis, the power grid is divided up into logical subnetworks.

NORTHERN AREA
- Largely residential property
- Local grid is supplied by 6 main power supply cables, 4 from the northern transfer station, 1 from the package substation and 1 from the southern 110/10 kV station
- Cable utilisation between 15% and 30% I_N

The northern area can be supplied easily with 4 cables.

SOUTHERN AREA
- Largely commercial and industrial zones
- Power is supplied via 6 main feeds, of which 3 are customers' cables
- One outgoing cable has reached the limit of its technical service life
- The maximum current is approx. 200 A (3.5 MVA)

SOUTH-EASTERN AREA
- Largely residential property
- Power is supplied via 2 cables, loaded to 20% and 40% respectively of capacity, also a number of unnecessary cross connections

CENTRAL COMMERCIAL AREA
- Power supplied to the centre via an interconnected grid with rings from the 110/10 kV station
- Some customer substations and also a section of the northern area have power supplied by the package substation
- Package substation loading is already 300 A
- Some cables carrying little current are routed long distances through the centre

The principle of the package substation should be limited in the projected design to supplying the commercial district. For supplying the city centre, on the other hand, a ring main system is preferable.

5.2 Optimising the power grid

5.2.1 Premisses for planning a projected power grid

A large customer is planning to establish a facility in CENTRAL COMMERCIAL AREA, to the south of the package substation, with a power supply capacity of 7.6 MVA. In the commercial area there are further areas which could be developed.

5.2.2 Current situation, optimisation of disconnects

The power grid model which has been produced and can be used for calculation shows the existing power grid structure together with the current disconnects. In an initial phase of the analysis the power grid simulation program is used to carry out an optimisation of disconnects: the procedure selects the switching state that has the lowest effective power losses, complies with all the secondary conditions (e.g. maximum load, voltage limits) and does not form any isolated subnetworks. This step alone has enabled effective power losses to be reduced by more than 20%.

5.2.3 Power grid optimisation in four subsections
Systematic technical replanning was carried out for each of the four grid sections. At this stage, the criteria and the projected designs for the individual sections can be altogether different. In any case, however, this demanding job requires a great degree of experience, a thorough understanding of electrical engineering and also a measure of creativity.

In summary, the results were as follows:
Based on the planning of the projected power grid, the large customer's site could be connected up with no additional power input and without the need to expand the package substation, at a financial cost of a mere € 60,000. The planning for connecting the customer without optimising the power grid had allowed for an investment sum of approx. € 400,000. The optimised version also performs excellently in that its operating costs are considerably lower, and yet it has sufficient reserves to cope with additional demand for power from the vacant commercial areas.
The whole system could be optimised as follows:

- Removing 2 circuit breaker panels
- Decommissioning approx. 10.5 km cable (representing 6.5% of total length)
- Removing 46 load-break switch panels from power grid substations
- Reducing renewal costs relative to 1:1 replacement
- Reducing annual operating costs
- Reducing susceptibility to failures (by decommissioning old cables)
- Minimising the average age
- Simplifying the power grid structure
- Reducing power losses by optimising disconnects

The overall economical result of the power grid replanning shows:

- Dismantling potential with annual operating costs of € 5,000
- Savings of € 1,265,000 in comparison with 1:1 renewal

6. OTHER OPTIMISATION POSSIBILITIES

A systematic recording and evaluation of the statuses of substations, such as that offered by RWE Rhein Ruhr Netzservice GmbH's inspection tool, would be worthwhile from the point of detecting and exploiting further optimisation potentials.
The density of substations in sections appears comparatively high. When considering loads and substation density, about 12 substations could be dismantled in the power grid investigated. No further analysis of the possible costs of changing cable or laying low-voltage cable was carried out. If the low-voltage power grid were further optimised, an even greater number of substations would become surplus to requirements.

7. SUMMARY AND OUTLOOK

The power grid described in the example is quite typical of an urban grid such as those found today in Germany and many other countries. Its low degree of utilisation and the large amount of equipment mean that there is generally plenty of potential for optimisation. By means of an additional systematic inspection and a 1-kV optimisation of the power grid, the overall system infrastructure can quickly be reduced by 10%. The implementation of the projected power grid should be carried out in an event-driven manner and in phases, based on economic viability calculations. Any opportunities for joint laying of services with other supply companies should be exploited.
A smaller infrastructure also leads to reduced maintenance costs and, at the same time, any equipment that is not installed cannot fail, thus the number of faults is reduced; an ideal projected power grid therefore also leads to a significant reduction in operating costs.

REFERENCES

[1] Dr. Johannes Stürmer, "*Instandhaltungs- und Erneuerungsstrategien in Verteilungsnetzen",* Shaker Verlag, Aachen 2002

[2] Edmond Petrossian, Theodor Connor, Eberhard Oehler, Jürgen Wolf, Sven Scherer, 2005, "Greenfield-Planung eines Versorgungsnetzes", EW Jg. 104 *Heft 8, 76 - 81*