PLANNING OF HIGH- AND MEDIUM VOLTAGE SYSTEMS IN URBAN AREAS

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SUMMARY

Although the fundamental aim of power distribution systems is to provide consumers with safe and reliable supplies of electricity, there are now also many political and social demands which, in turn, are necessitating firm emphasis on cost and environmental compatibility. In order to satisfy these somewhat contradictory requirements it is not enough to simply use the lowest-priced, good quality individual components; all items of plant and equipment must be chosen to work together as efficiently as possible. This is why careful planning of power networks is so important. Strategic system planning of this kind needs systematic procedures and experienced planning engineers working with backup from the most effective computer programs available. This article uses two examples to describe the planning strategies employed and the results obtained from specific planning studies.

PART A:

PLANNING OF THE MEDIUM VOLTAGE NETWORK OF STADTWERKE LEIPZIG GMBH

1. The starting point

Since the arrival of **ODIN** *(Optimized Dynamic Interactive Network Planning)* [1] it is possible to conduct complex performance analysis' for medium voltage networks taking not only into consideration the impact of future investment decisions [2] but as well the impact of existing losses in the current network [3] [4]. One good example for the excellent performance of the modern program system is the optimizing of the network of the Stadtwerke Leipzig GmbH. The consulting group in charge was able to conduct the complete network evaluation and optimizing within 7 months.

The medium voltage network of the Stadtwerke Leipzig GmbH consists of 15 transformer stations 110/10 kV and supplies an area of 149 km^2. At the time of the analysis 1680 substations (local network and client stations) were in use or planned. An estimated 1985 km of cables is necessary to supply them.

The existing structure of the medium voltage network is mainly characterized by the existence of ring networks, which are supplied through independent transformer stations. New planning concepts have to take into consideration the existing direct connections between the transformation stations, which are grown historically. Between the ring networks and the direct connections between the stations exist sometimes switch gears and further direct connections, which might increase the supply reliability, but which decrease the network transparency, and it is transparency, which is the base for a cost efficient management.

A great percentage of the ring networks still consists of cables with a standard cross sectional area of 50 mm^2 Cu or 95 mm^2 Al, which means a replacement due to

- higher load factors
- avoid bypasses
- increasing amount of network failures

might be necessary.

It was part of the long term planning of the Stadtwerke Leipzig GmbH to extend the existing network in an optimized manner in order to assure consistency of network capacities and actual demand. The task was to establish a long term concept, based on actual demand, and the development of trade and living areas as being forecasted by city of Leipzig until the year 2015.

2. Optimization of isolating points

Network losses will always occur due to physical reasons. The amount of losses is determined by the distribution facilities being used. A significant decrease of these losses is only possible with the use of newer and more advanced distribution technology. In open scale networks it is possible to optimize the usage of isolating points in order to minimize losses. However in historically grown networks with a large number of connections it is difficult to determine where these isolating points should be. Here occur losses which can be avoided in an optimized network structure calculated by the named program system.

This program system assures a transparent network structure and minimizes distribution losses while load factors and load variability remain within given limits.

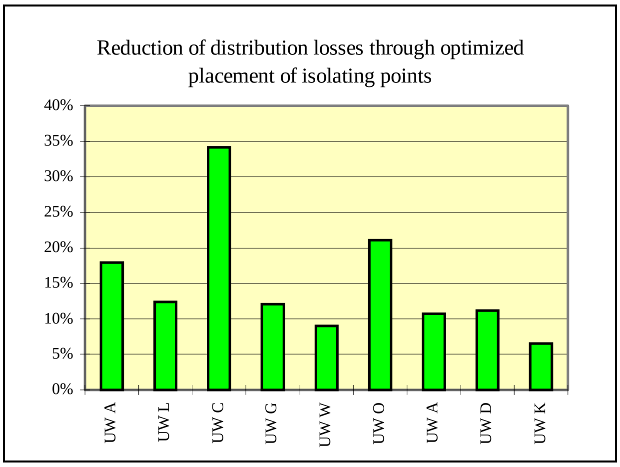
A considerable reduction of losses is in almost every network size and structure possible. Among the evaluated networks the possible decrease of losses was between 9% and 34%. **(picture 1)**.

The amount actually realized savings - i.e. where to place a isolating point - depends on

- accessibility of station
- condition of switch gears
- network structure
- time default in order to identify failures

However many cases show, that the transfer of switching stations is possible in order to minimize losses without questioning the network reliability.

An estimated 150 000 DM/p.a. in savings in the evaluated networks were realized due to a re-allocation of the isolating points within the existing network, i.e. without new investments.



picture 1

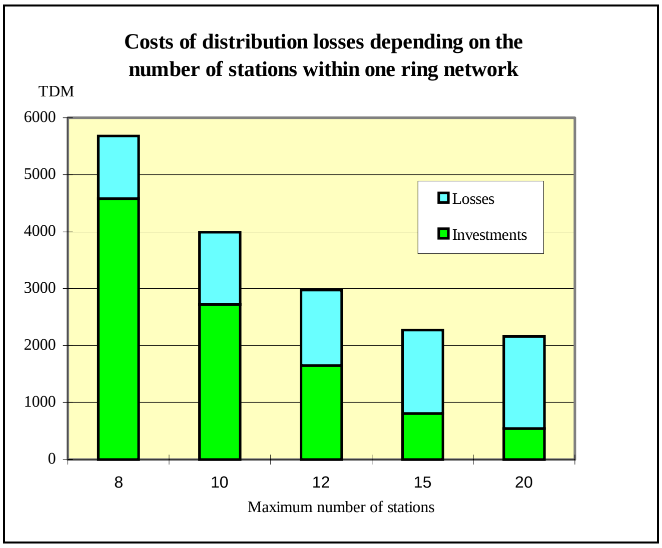
3. Network structure and planning defaults as determining variables in the extension of networks

3.1. Number of Sub-Stations and load factors within a ring network

One has to determine for the future extension planning, what the maximum load factor, depending on the standard cross sectional area of existing and planned cable strings, and what the maximum number of stations for one ring network are.

Investment decisions have to be optimized in order to satisfy existing capital restraints [5]. However this might lead to eventually higher losses than theoretically possible. The maximum number of stations within one ring network is determined by the demanded load factor per station. The allowed variability of electric supply is calculated based on the curb of tolerable labor slack according to Kaufmann based on the following inequality $P_u * t_u = 1000$ kWh; where P_u the amount of labor slack and t_u the amount of failure time resembles.

A load factor of 4 MVA and a maximum number of stations of 12 to 15 was determined under these boundary values for the planning of medium voltage networks **(picture 2).**



picture 2

Knowing the network structure and average load factor per station for the demanded planning period, one realizes that the increase of expenditures mainly affects networks with low load factors if the number of stations is limited.

> In other words, if the load factor per station is sufficiently high, only a limited number of stations per ring network is possible. That explains simultaneously, why there is no further reduction of expenditures possible once a number of 15 stations is reached. We reach obviously a natural border here for the maximum number of stations per ring network

The default of 12 to 15 sub-stations per ring network based capital restraints and the costs for distribution losses therefore seems to be reasonable compromise for the networks of the Stadtwerke Leipzig.

However it is possible in individual cases to accept a higher number of stations in order to satisfy capital restraints if the consumer profile allows a longer time for failure detection or the knowledge of local circumstances assures a fast failure detection.

Taking about the tolerable labor slack in the case of a power failure, one has to note that the load factor of a ring network is not positively correlated to the number of stations. The maximum load factor of a ring network as a whole is decisive. However it is probably unavoidable to assume a longer total time of power failure due to longer time needed to inspect a larger number of stations and the time needed for switching. We estimate a total time of 2 hours of power failure for a half-ring network with 6 stations. This seems to be reasonable. On average we estimate a much shorter time of power failure due to a faster failure detection. Normally the total blackout time for the individual customer will be the even shorter due to the normal increment of power per ring network, i.e. much below the tolerable amount of time. We further would like to note that the majority of cases of power failure does not occur during times of maximum load demand, therefore the average blackout time will be certainly below the tolerable time of labor slack.

3.2. Standard of cables

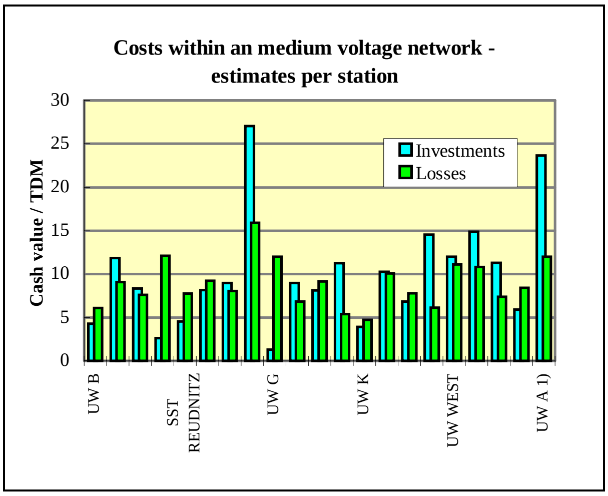
The standard cross sectional area for cables in the medium voltage network of the Stadtwerke Leipzig has been set at 150mm^2.

Currently are cables of the type NA2XS2Y 3x1x150mm^2 used. The transformation stations use a standard cross sectional area for cables of 240mm^2. Currently are cables of the type NA2XS2Y 3x1x240mm^2 used.

Generally speaking means a larger cross sectional area of a cable a decrease of distribution losses and or a higher load factor within a network. This leads to the question why one should not generally utilize larger cross sectional areas for cables in the distribution network in order to increase the load factor? A certain percentage of the existing cables has a cross sectional area of 50mm^2 Cu or 95 mm^2 Al. This cables have to be replaced anyway in the near future in order to secure a certain network reliability. The replacement could be cables with a standard cross sectional area of 240mm^2. Unfortunately consists the medium voltage network of the Stadtwerke Leipzig GmbH to a large degree of cables of the type NAKBA 185 mm^2 Al, which have an estimated life time, which is beyond the estimated planning period. The standard cross sectional area of these cables limits the maximum load factor of the medium voltage networks. A replacement of these cables would be uneconomical.

Higher load factors than with the type NAKBA 185 mm^2 Al are already with the cable type NASXS2Y 150 mm^2 achievable. Therefore it seems unreasonable to support the demand for a higher standard cross sectional area for the utilized cables.

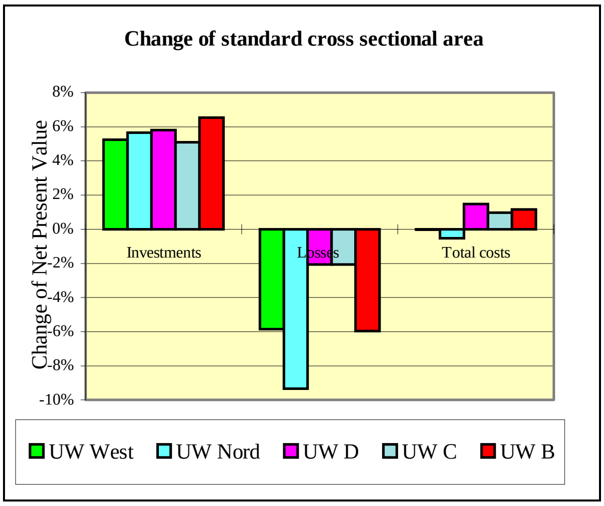
One aspect, which has to be considered is if the decrease in network losses compensates the higher costs for the new equipment of about 15 DM /m (material and labor costs).



picture 3

Using the program system it is optimized the amount of economical reasonable cable replacements taking into consideration the cable type and the replacement costs.

The results for selected networks are shown below **(picture 4)**



picture 4

The changes of the total costs of the investments are comparably small. The expected increase in total investments occurs (5% to 6,5% depending on the network). However the amount of savings due to a larger cross sectional area can be very different, depending on the analysis situs of the whole network, i.e. installation field for the cables and the load factor of the network.

4. Planning Results

Due to the evaluation and optimizing, the Stadtwerke Leipzig now dispose of a consistent and economically sound, long term concept regarding extension and replacement investments in their medium voltage network.

Based on the dynamic optimization it is now possible to classify investment decisions regarding

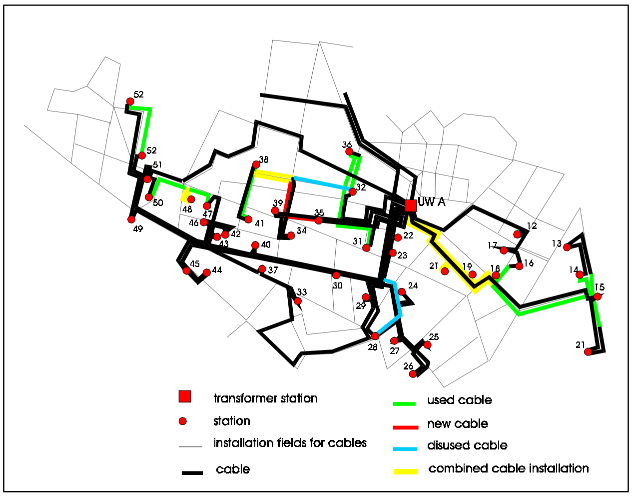
- anticipated date
- installation fields for cables
- possibility to combine the cable installation for the network with other later cable installations

The depiction of the network plan is either abstract or according to local conditions as a geographic network plan **(picture 5)**. A combination with a city plan is as well possible, which proved to be very handy.

4.1. Locations of Transformer Stations

One important result of the analyzes is the predetermination of the location of transformer station based on cost and network structure.

The quest for the location of new transformation stations tends to be difficult, especially in urban areas. It is implicitly necessary to verify the demand for a new transformer station since it means investments in considerable height. Reasons could be either the need for higher loads or the mutation of certain parts of the network. Alternatives within the existing network, e.g. supply via other transformer stations, have to be carefully evaluated.



picture 5

New investments should lead to a relief of the existing medium voltage network in the long run. If new investments are considered necessary, sensitivity analysis are implicitly necessary in order to assure the optimum solution regarding cost and network structure.

Normally several supply areas of different transformer stations are affected. The decision making process should take into consideration not only the additional costs of a new station but as well the new cost structure based on the interdependance with existing stations and the network structure as a whole.

4.2. Switching stations in the medium voltage network

Beside 15 transformer stations the Stadtwerke Leipzig GmbH run as well 7 switching stations within their medium voltage network. The condition and the size of these switching stations varies. However for all stations seems in the short and medium run the replacement of either shell and/or electric equipment mandatory.

For larger switching stations, which have the potential to be converted into full scale transformer stations at a later stage, is the restoration and sanitation recommendable. However for smaller stations it is questionable whether the added value justifies the amount of investments necessary for restoration and sanitation (average of about DM 900 000 per station).

Using the program system, we calculate the impact of the closure of switching stations regarding

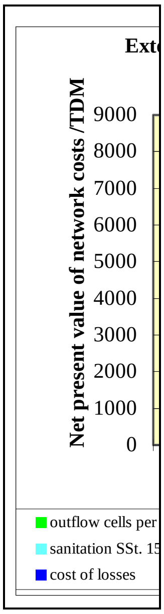
- the number of outflow cells necessary per transformer station
- future network extensions
- network losses

The additional costs for the network were compared with the investment costs, mandatory to continue operating a particular switching station **(picture 6).**

One has to note that the additional costs due to slightly higher network losses and additional outflow cells necessary per transformer station are more than compensated by avoided investment costs for the sanitation and restoration of a switching station. In the case of one supply area are the estimated savings about DM 1,1 Million.

Based on our expertise, it is at least for smaller switching stations more profitable to close them down.

Regarding the network management it is recommendable to anticipate a clear and transparent network structure. Yet, one has to take into consideration that the supply of critical, major clients, such as public transportation, especially urban railway network, does not lead to unallowable network retroactivity.



picture 6

5. Conclusion

The examination of a large number of planning alternatives, calculated by ODIN allowed the Stadtwerke Leipzig GmbH to establish within 7 months a detailed medium and long-term planning concept for their medium voltage network with clearly specified annual investments.

Besides the revision of all the plans for the medium voltage network it is now possible to estimate the essential investments and to coordinate these with other builders such as telecommunication etc.. Since the investments are clearly structured and listed on an annual basis it is possible to estimate investments not only on an overall basis but as well on a short term basis. Especially the next five years are important since the recommended measures during this time scale seem to be most likely to be actually realized. The long term measures should be seen as recommendations to be carefully re-evaluated at a later stage in order to be consistent with the actual realized development regarding demand for load factors etc..

The consistent establishment of ring and line connections assures a transparent network structure, an efficient network management, and shortens the search time in case of network failures. Due to the optimized allocation of switching points or disconnectors within the network it is possible to realized estimated savings of about DM 150 000 p.a. . After an initial data recording additional sensitivity analyzes and examinations are normally much less costly regarding time and effort. Therefore it is quickly possible to react to new developments.

An annual revision of all planning documents is done based on the re-examination of

- annual sales of electricity
- load increase
- failure analyzes

The results of sensitivity analyzes and examinations, such as the one using ODIN carefully described above, are clear advantages for the network planning. Especially the advantages regarding the reliability of the established planning concepts are remarkable.

Further it is now possible with the employment of the latest planning technology to analyze and to optimize complex problems in a quantified manner which was not possible in the past. Similar results are obtainable using a planning system for low voltage networks IONN (Interactive Optimized Low Voltage Network).

Additional literature Part A:

[1] *Kaufmann, W.: ODIN - ein neues Programmsystem für die rechnergestützte Netzplanung und weitere vier Aufsätze. Elektrizitätswirtschaft 88(1989), H.3, S.103 - 132. (ODIN an new computer program for IT based network planning)*

[2] *Kaufmann, W.: Rechneroptimierte Ausbauplanung von Mittelspannungsnetzen. Elektrizitätswirtschaft 89(1990), H.6, S.271 - 279. (IT optimized extension planning of medium voltage networks)*

[3] *Burgardt, W.; Kaufmann, W.; Sporbert, L.: Mittelspannungsnetzgestaltung unter Verwendung von ODIN. Elektrizitätswirtschaft 95(1996), H.4, S.178 - 181. (Configuration of Medium Voltage Networks using ODIN)*

[4] *Kaufmann, W.: Planung öffentlicher Elektrizitäts-verteilungs-Systeme. VDE-Verlag GmbH, Berlin, und Verlags- und Wirtschaftsgesellschaft der Elektrizitätswerke mbH, Frankfurt am Main, 1995 (Distribution systems for electricity)*

PART B:

PLANNING OF HV AND MV NETWORKS OF WUPPERTALER STADTWERKE AG (WSW)

1 The starting point

Wuppertal these days is a major conurbation with a population of nearly 400,000 people. It originally came into existence in 1929 as a result of the unification of several local towns and communities which, until then, had been independent units.

As long ago as 1887 the supply of electricity to the people of Elberfeld was introduced as one of the communal duties of the municipal authorities. Later on, all the other local districts followed the same pattern. Thus, when Wuppertaler Stadtwerke AG (WSW) was founded in 1948 with the task of supplying power to the whole of Wuppertal, it inherited distribution systems with operating voltages of 5 kV, 7 kV and 10 kV and transmission networks of 25 kV, 35 kV and 50 kV.

Following the changeover to a uniform distribution level of 10 kV and a new transmission level of 110 kV, most of the existing substation sites continued in service.

Wuppertal satisfies its demand for power (peaking at around 400 MVA) partly from its own three generating plants and partly from the 220/380 kV grid at two locations. The power is distributed around the city from the 110 kV network and fed into the 10 kV network through 13 transformer substations. The total area receiving power supplies is approximately 190 km^2.

Since rapid growth in the demand for power had been continuing for many decades, all future transformer substation sites were originally built and used as 10 kV primary distribution stations (switchgears with circuit-breakers). However, when the growth in consumption tailed off drastically as a result of the world oil crisis, energy-saving measures and environmental factors, the question arose as to how the 110/10 kV network should be configured for the long-term future. In addition to the task of providing a secure supply of power there was also the problem of designing a network that would be as efficient and as cost-effective as possible. Before any switchgear and other equipment was renewed it had to be absolutely certain that it would still be needed in the future. Furthermore, the 10 kV network was also to be of a much clearer and simpler configuration.

Therefore, the task was to develop a new, long-term concept for the 10 kV and 110 kV networks taking the following factors into account:

- Structural changes in the development of loads
- Enlargement of the supply area
- The large amount of plant and equipment needing updating
- More flexible arrangements for power infeed.

The basic planning has been carried out for two load stages - in 2000 and 2012.

The planners are using the Siemens SINCAL system planning and documentation system which enables networks in the form of both schematic diagrams and topological network plans to be processed [1]. The three methods of “load flow”, “optimum sectioning points” and “short circuit” are available for use.

2 Basic planning procedures

The starting point for the basic planning is an analysis of the existing power supply system. The actual status of the plant and equipment, energy demand and geographical factors are described. The preconditions for planning (e.g. the individual load development in different areas) are specified in relation to internal and external peripheral conditions.

The limits of the ability of the network (e.g. maintaining maximum permitted load currents and fault currents) are examined by problem analysis and any potential bottlenecks are pinpointed. On the basis of appropriate principles of supply, various alternative concepts for the network are drafted, analyzed and evaluated. In optimizing the concepts these steps are repeated as many times as is necessary. Any higher-level or lower-level networks must be taken into account at the same time of course.

This creative process of drafting and evaluation is the planners’ real task. Although they can receive a certain amount of help from automated methods, the fact that the process is never totally objective and clear means that the final decision on which alternative should be used has to be made by the person in charge.

The aim of the basic planning is to achieve a concept for a network that will be as economic and efficient as possible throughout its service life, that will be easy to plan, design and operate, will adapt easily to any changes in requirements and will ensure power supplies of appropriate quality. Depending on how long the plant and equipment can give useful service, a period of approximately 20 years is usually chosen for the period of planning.

The actual implementation of the network concept developed during the basic planning takes place at the construction planning stage. For a period of up to 5 years concrete measures are laid down covering, for example, the structure of the network, construction, conversion and reduction works and the financial requirements [2].

3 10 kV system planning

3.1 Network analysis and load forecasting

All the 110/10 kV transformer substations are equipped with redundant transformer and double busbars.

The 10 kV network is basically a cable-string network between substations which allows a very flexible system operation. However, the 12 primary distribution stations (with circuit-breakers) and numerous 10 kV network nodes (switchgears with load-disconnectors) that the system now contains result in a very complicated network structure. Many of these stations need to be updated or renewed.

The total length of 10 kV cabling in the network, including some overhead lines, is approximately 1300 km. The standard cross sectional area for cables has, for many years, been set at 240 mm^2 Al. In all, there are approximately 1600 network substations and special-tariff customer substations throughout the city to which power has to be fed.

The analysis of the network has revealed that in certain subdistricts - especially in the north of the city - reliability of supply is badly compromised because of the lack of clear and adequate alternative switching options, should any of the cables suffer failure. In addition, a few parts of the network receive their supply from relatively distant transformer substations which leads to high losses in the network.

These days, reinforcement of networks is no longer caused mainly by a global load increase but by local load changes and system updating. Therefore suitable concepts of supply are becoming more important because the consequences of mistakes in capital investment now last much longer than before. System planning offers an opportunity to simplify the structure of the 10 kV network so that losses too can be minimized.

In order to analyze the development of loads throughout the city on the basis of both place and time, individual power supply districts have been defined according to natural boundaries (such as rivers, railway lines, motorways, open spaces, etc.). In total there is an average growth in load of approximately 1% per annum, mostly as a result of special-tariff customers. In addition there is a need to supply a new area with a peak load of around 10 MVA. Fig. 1 shows the total supply area and the individual power supply districts in relation to the river Wupper as well as the new supply area due to the absorption of other networks.

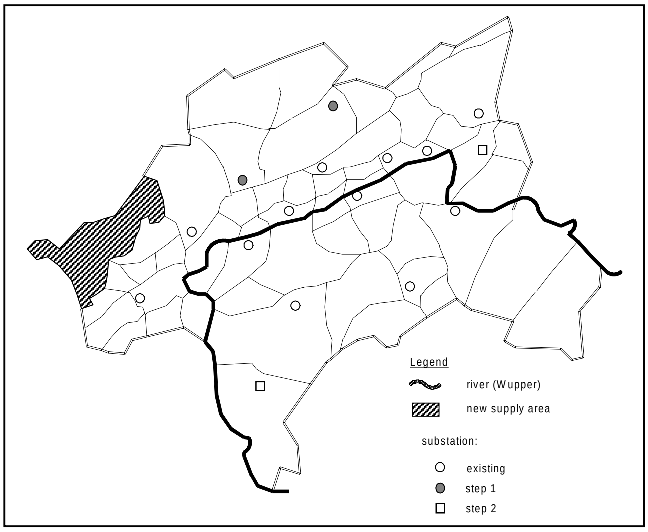


Fig. 1: Power supply districts

3.2 Future concept of the 10 kV network

On the basis of experience gained from numerous previous system planning projects, the following planning criteria were agreed with the Wuppertaler Stadtwerke AG and used as the foundation for the further development of the concept for the 10 kV network:

- a power infeed of maximum 40 MVA for each 110/10 kV transformer substation
- a line- or ring load of about 4 MVA with up to 15 distribution substations
- 240 mm^2 Al as the standard cross sectional area for any new cables laid
- simplification of the network by reducing the number of switchgear stations
- minimization of losses by optimizing the location of network sectioning points.

Various alternative options for the 110/10 kV infeed points required and the relationship of the individual power supply districts to the transformer substations were worked out and evaluated from both technical and financial standpoints by the WSW/Siemens planning team. The chosen variant was then employed for detail planning of the 10 kV network.

Geographical plans of the 10 kV network and structural plans were employed to carry out the system planning and for presentation of the results [3]. The changes in the transformer substation districts and their loads are illustrated in Figs. 2 and 3 (with values quoted in MVA) taking the first stage of expansion as an example.

Analysis of the present network, the forecasting of future loads and WSW's previous operating experience have led to the predominant need for continuous cable-strings between the transformer substations in order to simplify the 10 kV network. In some cases (e.g. in peripheral areas), cable-strings to remote substations or ring systems have also been used, because this was the more cost-effective solution.

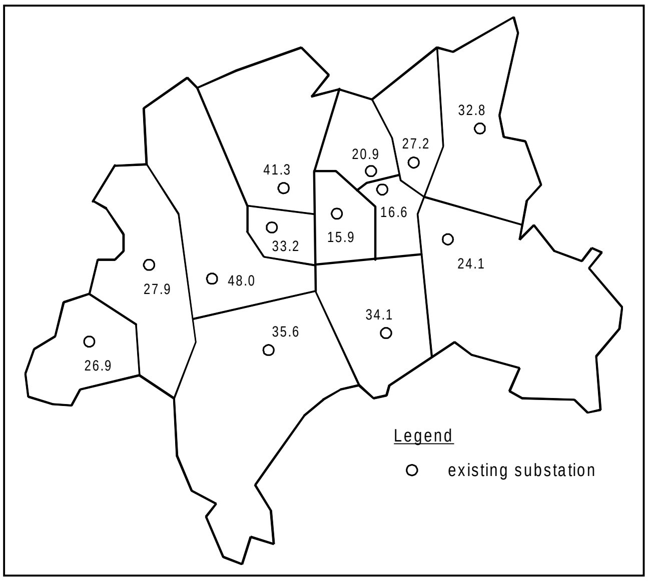


Fig. 2: Substation districts in 1992

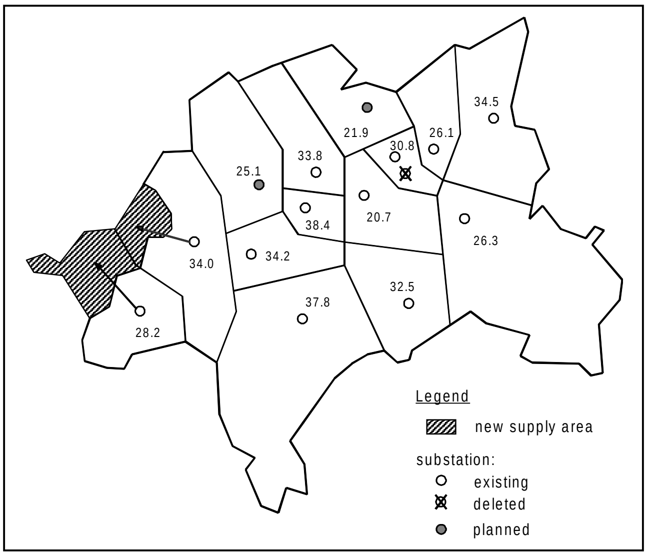


Fig. 3: Substation districts in 2000

The planning showed that most of the 10 kV switching substations and remote substations that need to be updated or renewed could be deleted during the course of simplification, and without the need to lay many new cables. It meant the saving of around 12 million DM on the total cost for renovation of plant and equipment.

Of the 12 existing 10 kV network switching substations (with circuit-breakers) only 4 will be needed in future. One transformer substation needing renovation will no longer be needed in the future and so can be dismantled. The planning work has also shown that another of the transformer substations is in a very unfavorable position, geographically speaking. However, since the 110 kV switchgear of the station and the 110 kV feeder cables were renewed only a few years ago the site will have to remain as it is for the time being. Unfortunately, the results of the study in this case came about 10 years too late.

The analysis of the 10 kV network shows too that the north of the city needs two new transformer substations (Brill and Hatzfeld) which should be built as quickly as possible. With these transformer substations it will be possible to simplify the structure of the 10 kV network even more and, in total, 10 of the existing switching substations and remote substations in the present system can then be eliminated.

For load stage 2 the building of one or two more transformer substations will be necessary, depending on how demand grows. Since no clear decisions on sites for these substations can be taken at present, it has been decided to acquire suitable land at potential sites. The actual decision on the building of the transformer substations, however, will be deferred for as long as possible. It was also decided to update the fundamental network study after a period of about 10 years.

4 110 kV system planning

4.1 Preconditions for planning

The starting point for the study of the Wuppertal 110/50 kV network is the configuration shown diagrammatically in Fig. 4. The WSW 110 kV network also supplies the town of Velbert and, in addition, at the Schwelm transformer substation there is a connection to a 110 kV sub-network belonging to AVU (Aktiengesellschaft für Versorgungs-Unternehmen) with the result that the 110 kV network has to carry a total load of approximately 650 MVA.

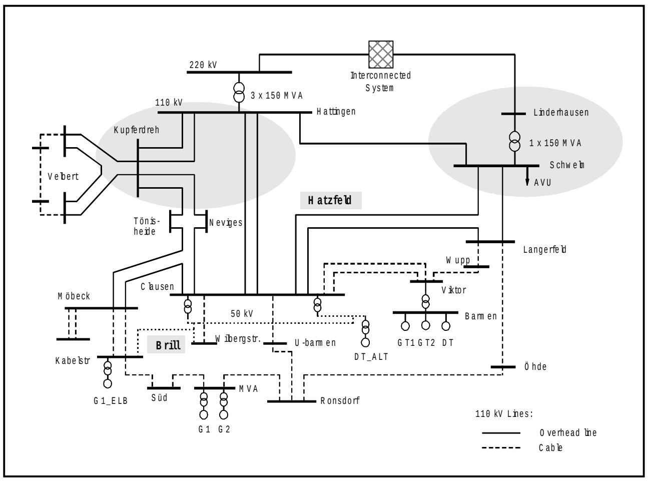


Fig. 4: Diagram of the 50/110 kV network in its present form

The 110 kV network comprises a two-to-one mix of overhead power lines and cables with a total length of nearly 200 km. Further expansion of the network will involve the use of overhead lines if possible or gas-pressure cables (630 mm^2 Al).

Wuppertaler Stadtwerke operates the Barmen and Elberfeld district heating power stations which have an installed capacity of approximately 200 MW. Additional in-house capacity is provided by a refuse incineration plant which also feeds into the 110 kV network. The basic planning was based on a minimum in-house generating capacity from the three power stations of 95 MW and a maximum figure of 197 MW.

The 110 kV network is linked to the 220 kV grid at the Hattingen transformer substation through three 150 MVA transformers. A link between the 220 kV and 380 kV networks is provided by a 600 MVA interconnecting transformer. The second infeed at Linderhausen via a 150 MVA transformer has no 220 kV switchgear.

The planning of the high-voltage network has taken into account the reduction of the 50 kV network, the building of new 110/10 kV transformer substations depending on the requirements of the medium-voltage network and the upgrading of the 220/110 kV grid infeed to 380/110 kV. The system planning uses the n-1 criterion, whereby the simultaneous failure of two systems of a multiple overhead power line installation also has to be considered.

4.2 The planning task

The existing 110 kV network has to be analyzed on the basis of the load figures provided by the 10 kV system planning and the limits of capacity that have been ascertained. Further expansion of the 110 kV network is planned for two stages in 2000 and 2012. Network concepts will have to be developed for each individual stage together with appropriate measures for upgrading the 110 kV network according to the growth in demand and in-house generating capacity. The most important aspects of the planning work are greater flexibility of the infeed arrangements in the areas marked in Fig. 4 and the effective linking-in of the new transformer substations at Brill and Hatzfeld.

The choice of options and all the associated technical and financial evaluation is being carried out by a joint planning team formed from staff from both WSW and Siemens.

4.3 Analysis of the present network

The 110 kV network was analyzed from the aspect of capacity employing load-flow and fault-current calculations in the SINCAL program. The analysis revealed that, with minimum input from in-house power stations, the transmission lines and feeder transformers of the 110 kV network will be carrying a very high load even under normal operating conditions. Due to the network configuration and the parallel operation of overhead lines with different conductor configurations (single conductors and two-conductor bundles) in the Hattingen-Kupferdreh-Clausen area, there are substantial differences in the loads being carried by these north/south lines. Maintenance and fault repair work on the subsections where four systems are strung on the same pylons necessitates the de-energizing of the systems in pairs, which can sometimes give rise to certain restrictions in service.

The overloading of lines and transformers that can occur as a result of plant and equipment failures could of course be avoided by increasing in-house generating capacity but it has also been discovered that the transmission capacity of the network has already reached its limit and there are no more reserves available.

4.4 Development of network concepts

Network concepts are being developed and studied which, it is hoped, will improve the loading of plant and equipment under normal operating conditions, restrict the amount of overloading in the event of plant and equipment failure and improve the security of supply. The alternative options that have been developed are being evaluated and optimized from the aspect of technical feasibility and economic performance. The following measures aimed at improving power flow sharing in the Hattingen-Kupferdreh-Clausen area have been studied:

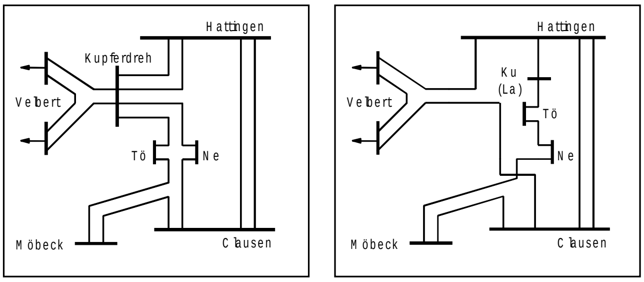
- Changes of circuit-impedance
- Directional operation of transformers
- Changes in circuit and network configuration.

Effecting changes in impedance, e.g. by installing a series reactor or a series capacitor and employing directional operation of transformers offers prospects of being able to reduce the problems that currently exist in the Hattingen-Kupferdreh-Clausen area. On the other hand, they do not represent an appropriate long-term solution from either the technical or economic standpoint.

Therefore, the 110 kV network in the Hattingen-Kupferdreh-Clausen area has also been examined from the point of view of possible changes to the configuration or other modifications to the network. Thus, as an alternative to the Kupferdreh transformer substation, whose 110 kV and 10 kV switchgear has been earmarked for upgrading, a new 110/10 kV transformer substation at the load center in Langenberg is being considered which should allow the losses in the 10 kV network to be reduced quite considerably.

Of the many ideas put forward for modifying the networks, detailed discussion of the various advantages and disadvantages involved has given rise to planning concepts which have been studied as to their effect on load flow sharing and on the security of supply under normal and fault conditions.

The design variant illustrated in Fig. 5 is the result of changes to the overhead-line and transformer substation configuration in the Hattingen-Kupferdreh-Clausen area. Its advantages are that it can be implemented at short notice, it requires only low investment and the load flow sharing between the various circuits involved would be greatly improved.



Present network **Design variant**

Fig. 5: Ways of expanding the 110 kV network

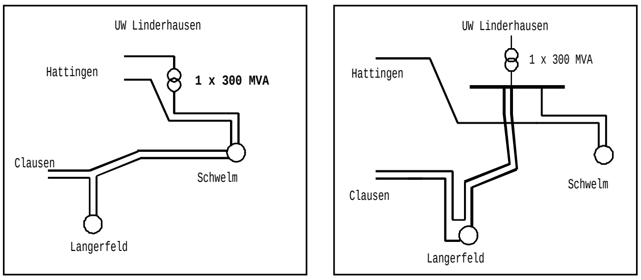
Taking the results of the medium-voltage system planning as a starting point, the development of a concept for the 110 kV network needs to make allowance for the building of new 110/10 kV transformer substations. Stage 1 of the system planning involves substations at Brill and Hatzfeld (Fig. 4). The concepts developed have been analyzed by means of power flow calculations and evaluated according to their investment costs and peripheral operating factors.

The linking-in of the new 110/10 kV transformer substation at Brill will employ a new cable link between the Wilbergstraße substation and the Kabelstraße substation which will make use of existing empty ducting. Expansion of the network in this area will reduce the load on the network in the south and allow reduction of the 50 kV network.

The new 110/10 kV transformer substation at Hatzfeld can be linked into the Clausen-Schwelm line or into the Clausen-Langerfeld line. The governing factor is the future development of the eastern part of the 110 kV network.

A study of the infeed conditions from the grid showed that, in the event of power line or transformer failures in the 110 kV network, it would be possible for the 150 MVA transformer at Linderhausen to be overloaded. Regardless of how the 110 kV network is developed in the west, therefore, it will be necessary to reconfigure the second grid connection at Linderhausen.

In the case of the variant shown in Fig. 6, the first stage would involve strengthening the Linderhausen infeed with a 300 MVA transformer. In the long term (Stage 2) the best alternative from the technical and financial aspects is to separate the WSW and AVU infeeds in the new 110 kV switching station to be built at Linderhausen while simultaneously upgrading the existing Linderhausen-Schwelm-Langerfeld link.



Step 1 **Step 2**

Fig. 6: Arrangements for the Linderhausen infeed

5 Conclusions

Due to the long service life of plant and equipment and the very low rate of growth in the demand for electricity these days, capital investment in power supply networks needs careful forward planning and coordination. Consequently, the latest methods employed in the planning of power supply networks incorporate reduction measures as well as expansion and remodeling. Since there are no ready-made solutions for system planning, experienced planning engineers are needed, who are supported by an efficient network planning and documentation system.

During the basic planning stage, a number of concepts were developed for the 10 kV and 110 kV networks of Wuppertaler Stadtwerke AG which were then selected and evaluated by a joint planning team of WSW and Siemens staff. The economic optimum was only to be achieved by considering both voltage levels together.

Successful implementation of the planning recommendations is already in progress. In the Hattingen-Kupferdreh-Clausen area changes to the circuits have been made, one of the substations, needing renovation, has been eliminated and the new Brill substation has been built. The approval process for the Langenberg and Hatzfeld substations has been initiated and remodeling of the 10 kV network and realignment of the 10 kV sub-networks are currently in hand. Simplification of the structure of the 10 kV network is allowing a saving of approximately DM 12 million on upgrading costs as well as reducing losses in the networks.

6 References

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