DISTRIBUTION NETWORK PLANNING FOR HIGH LOAD DENSITY AREAS

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ABSTRACT
In many emerging countries, like on the Arabian Peninsula or China, new cities are planned and built from scratch in areas with no existing infrastructure. The load density is expected to become very high within the next 10 to 15 years. To handle such high load densities network structures for the distribution networks are required which are characterized by a very high flexibility and scalability. Based on the example of Dubai Waterfront planning steps for such networks are presented and explained.

INTRODUCTION
In many emerging countries new cities are planned and built from scratch in areas with no existing infrastructure. As for these new cities a high standard of living is expected and they are often built in regions which require air conditioning, the load density is expected to be very high. For examples at the Arabian Peninsula load densities in the range of more than 50 MVA/km² of peak load are expected within the next 10 to 15 years. These high load densities require network structures which are characterized by a very high flexibility and scalability as the future loads and their distribution cannot be predicted exactly and a forecast error of only ±10% means a difference in the predicted load density of ±5 MVA/km². This itself would exceed the total load density in a typical European city, like Berlin with a load density of approximately 3 MVA/km² in average. It is an extraordinary challenge to the flexibility of a distribution network to handle such prediction errors. The customers in such high load density areas usually also have high requirements regarding the reliability of supply. In such areas there is a high dependency on the electrical power supply (e.g. elevators, lights, air conditioning).

Because of the presently non-existing infrastructure there are no restrictions for the new networks. Therefore now there is the unique chance to build networks which will be able to fit the needs of the grown cities in the future and are highly flexible to react on developments which might be considerably different from the planned ones. If the city has been built then later major changes in the electrical infrastructure are very difficult if not impossible.

In the paper a network design based on the principles of yellowfield planning for the area of Dubai Waterfront is presented. The considered area is illustrated in figure 1.

The planning was performed for the distribution, subtransmission and transmission network together to optimise the total system [1]. This holistic planning approach ensured that the network structures in the different voltage level fit together and there are no constraints posed on the decisions in one voltage level by already fixed decisions in another voltage level. Based on the focus of CIRED in this paper only the planning of the distribution level is presented.

PLANNING PROCEDURE
Planning steps
For the planning of Dubai Waterfront the steps as explained in the following sections were performed. The topics called “definition of” are mainly determined by external factors. The network planning does not have the possibility to influence these factors considerably. Therefore they will be defined in the beginning of the planning and then will set the framework in which the planning work will take place.

In the following sections the different criteria are evaluated based on the example of the planning project for Dubai Waterfront. The reasons behind the selected solution are explained. General rules and guidelines are derived to be applied for similar requirements.
In the areas under consideration – fast developing regions with high expected load densities – the load growth factors will be very high. The load growth starts from a very low level, sometimes zero, if the area is still desert. Therefore typical load growth factors can be several hundred percent per year for many years. At the beginning of the development of such a new area there is no infrastructure available which limits the construction works. Everything can be built on a “yellow field”. Later changes in the firstly built infrastructure are then difficult if not impossible because of the developed other infrastructure.

Therefore for such a yellow field project it is essential to consider the final development stage at the very beginning. Based on this long term concept the first development steps can be selected. This approach (planning loop, see figure 2) assures that the right investments are done early enough and stranded investments as well as stress situations due to overload are prevented. Typically a planning horizon of at least 10 to 15 years is chosen. For Dubai Waterfront the long term planning stage was decided until 2023.

The load on the low voltage level typically has a quite low coincidence factor. From the installed load at the low voltage level only 50 % to 70 % has to be supplied by the distribution network at the same time during the peak load condition. The cooling load can have a coincidence factor of 95 % or higher. As the peak load in these areas usually occurs during the hottest period nearly all air conditioning devices are in operation at this time.

For Dubai Waterfront for the year 2023 an average density of the installed load of app. 120 MVA/km^2 is expected, with more than 150 MVA/km^2 in the central areas. This evaluates to a connected load per inhabitant of app. 3.5 kVA (compared to app. 1 kVA/inhabitant for Berlin). Approximately 30 % of the load is cooling load. This load has to be supplied by the distribution network.

**Definition of expected spatial load density distribution**

With such high load densities, the distribution networks will not cover a large area. Therefore a quite detailed knowledge about the spatial load density distribution is needed. During the early planning stage such information might be difficult to obtain but for the distribution network planning such information is essential.

To describe the spatial load density it is recommended to divide the area under consideration in sectors for which a similar customer structure is expected, like offices, flats, shopping areas, public buildings, industrial areas. For each sector the total load is predicted. As it can be assumed that the load density distribution will be even within the sector, the average load density can be calculated easily. The size of such a sector depends on the structure of the area. If it has a homogenous customer structure, the sector can be large, if it has a heterogeneous customer structure, the sector has to be smaller.

A map containing the different sectors together with their according load will be the main basis for the planning work.

**Definition of positions of infeeds**

The substations containing the HV/MV transformers supply the power to the distribution network. Therefore their position has to be known for the planning of the distribution network.

If the subtransmission network does not yet exist, as it is often the case for the newly built cities, it is recommended that one planner plans the networks for all voltage levels (except the low voltage level) in one area together using a bottom up approach. This ensures the optimal matching between the subtransmission network and the distribution network.
As the structure of the low voltage network is mainly determined by the individual loads it has to be planned by the planner of the individual building. At this early planning stage it cannot be included in the yellowfield planning of the power supply networks.

**Definition of the criteria for the reliability of supply**

The structure of the network will be determined by the criteria for the reliability of supply. Theoretically it would be possible to design a network to meet a certain value of a reliability parameter (e.g. SAIDI). But in practice such an approach does not make sense. The statistical fault parameters (e.g. number of outages per kilometre) for the network are not known because it does not exist. On the other hand the outcome of such an approach will probably be a network structure which is different for each supply area and will violate other planning criteria (like simplicity).

Therefore for yellowfield planning it is best practice to apply the (n-1)-criterion for the planning. This means that any element in the network (e.g. line, transformer) can fail but all loads (except the faulted one) can still be supplied. Some switching operations might be necessary to re-establish the supply. For important customers the (n-1)-criterion can be extended to the (n-2)-criterion. Depending on the importance of the customers the fault of a busbar at a substation or the fault of a total substation can be included into the (n-1)-criterion.

The amount of distribution automation also influences the reliability of supply. Automation of at least the crucial substations and ring main units leads to an optimal level of reliability.

**Selection of appropriate voltage level**

The selected voltage level for the distribution network will be determined mainly by 3 criteria:
- load to supply
- short circuit level
- availability of equipment.

The voltage level and the size of a supply area are interrelated. In high load density areas the size of the supply area is limited by the maximum power to supply not by the maximum distance to cover.

The maximum power to transport is limited by the maximum cable size. The maximum cable size which can be handled in the medium voltage level is in the range of 300 mm$^2$. If one assumes an economical current density of 1 A/mm$^2$ then a 300 mm$^2$ cable can carry maximum 300 A. Depending on the voltage level this evaluates to a transferred power as given in table 1.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4 kV</td>
<td>0.21 MVA</td>
</tr>
<tr>
<td>11 kV</td>
<td>6 MVA</td>
</tr>
<tr>
<td>22 kV</td>
<td>11 MVA</td>
</tr>
<tr>
<td>33 kV</td>
<td>17 MVA</td>
</tr>
<tr>
<td>132 kV</td>
<td>69 MVA</td>
</tr>
</tbody>
</table>

As the losses in a cable are current dependent, they do nearly not depend on the nominal voltage of the cable. Therefore related to the same transferred power, the losses in a 33 kV cable are only app. 1/3 compared to the losses in a 11 kV cable because in the 33 kV cable the same current transfers 3 times the power.

If a system is operated with twice the voltage compared to another system then app. 2 times the load can be connected to reach the same short circuit current level.

Based on the availability of equipment for the distribution level this mainly will be the decision between 10 (11) kV or 20 (22) kV. For higher voltages, e.g. 33 kV, the transformers to the low voltage level become too expensive.

Based on the above mentioned reasons for the Dubai Waterfront area the 22 kV level was chosen as preferred option.

**Selection of appropriate HV/MV transformer ratings**

For the transformers three main parameters have to be determined:
- rated power
- short circuit impedance
- vector group

The selection of the vector group is influenced by the handling of the neutral grounding, which is not discussed within this paper.

The minimum total amount of transformer power to be installed in one substation is the sum of the loads to supply plus the reserve needed to handle a transformer failure. From this example it can be seen that the criteria cannot be looked at independently but all of them have to be investigated in a holistic approach. The reserve needed to handle a transformer failure is determined by the reliability criteria and the structures of the network and the substation.

The maximum amount of transformer power to be installed is given by the rated current of the MV switchgear and by the short circuit withstand current. With a rated current of 4000 A the maximum total transformer power at the 22 kV level is app. 150 MVA. If all transformers are operated in parallel and a short circuit impedance of $u_k=16\%$ is
assumed than switchgear with a short circuit withstand current of \( I_{sc} = 25 \text{ kA} \) is needed. If the contribution of the low voltage motors to the short circuit current is considered, the maximum short circuit current will be higher. This means, not all of the installed transformer power can be operated in parallel.

Based on the preferred network and substation structure (see below) it is decided to operate 3 transformers 50/75 MVA in one substation with a firm capacity of 150 MVA.

### Selection of the appropriate MV/LV transformer ratings

The rating of the MV/LV transformers depends on the load requirements of the specific clients. With a load density of 120 MVA/km\(^2\) a transformer with a rating of 1 MVA supplies an area of app. 8300 m\(^2\), which is equal to a square 91 m x 91 m. This means that on average each 90 m one RMU is needed, thus in every high rise building.

As a compromise between distance of RMUs and short circuit power as well as numbers of outgoing LV-feeder a rating of 1 MVA is recommended.

### Selection of network structure

The selected network structure should fulfil the following targets (without any ranking):
- reliable power supply
- flexibility in operation and development
- low loss level
- easy adaptation to the actual load development
- simple operation and control
- optimized investment costs

As for the developer investment cost, scalability and a simple operation and control are important criteria the structure “Express feeder” is proposed for the distribution network. The special characteristics of this structure are:
- It is simple. For each fault scenario there is exactly one and always the same strategy: 1. isolate the fault; 2. close the according switch in the remote switching station.
- The (n-1)-criterion is fulfilled.
- The feeders can be loaded up to 100 % (except the express feeder, which may not be loaded at all under normal conditions)
- There is an express feeder needed.
- A remote switching station is needed. This remote switching station can easily be extended to another substation, if the load in this area exceeds the predicted value. The network structure then changes to “Feeder between substations”.

### Selection of the standard cable

For the high load densities cables with high current carrying capacities are needed. But the larger the cross section the more difficult a cable is to handle. As a compromise single core XLPE copper cable with a cross section of 240 mm\(^2\) is proposed. For the conditions in Dubai a permissible loading of 9 MVA at 22 kV is determined.

### Selection of substation structure

Because of the simple network structure the substation structure can also be simple. To fulfil the (n-1)-criterion (except for a fault at a busbar) a single busbar with sectionaliser is sufficient. It is recommended to install gas insulated switchgear. This reduces the space requirements, which are crucial for the installations in such areas. It also reduces the probability of a fault at a busbar allowing the use of a single busbar structure.

### PLANNING RESULTS

Based on the above mentioned planning procedure a network was designed which is illustrated in figure 3.

[Figure 3 Principle of distribution network structure](#)

This proposed network structure allows an efficient and reliable supply for high load density areas providing sufficient flexibility to react on load developments different than predicted.

### REFERENCES