# THE TOPOLOGY OF SELF-SUSTAINING GRIDS REGARDING RELIABILITY AND COST: FROM RESERVE TO SMART GRID

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## *ABSTRACT*

*In recent years, the Smart Grid is a subject of broad interest. The electric utility of Zurich, ewz, is involved with the topic in a secondary grid project. The root of the secondary or reserve grid as realized in the pilot project consists of a medium voltage ring network. It is planned to develop this system in several steps to a grid with self-sustaining power supply. Consequently, various topologies of secondary grids are compared regarding reliability and cost. The results show that the reserve grid can be an alternative to an emergency power supply provided by diesel generators regarding both reliability and costs. The economic advantage depends on the customer structure and the topology of the reserve grid.*

## INTRODUCTION

The basic concept of a secondary grid, which combines redundant supply for customers needing emergency power supply with distributed generation, has already been presented in a first publication [1]. Building on this basis, this paper presents an approach to the implementation of a secondary grid. The following questions are addressed:

- Various network topologies are possible: What is the impact on reliability and costs?
- In the pilot project, low voltage customers receive a redundant connection in form of a single feeder to a transformer station of the secondary grid: Would it be worthwhile to construct also a secondary low voltage network underneath the self-sustaining medium voltage network?
- How shall the secondary low voltage grid be operated? An operating voltage above the common 0.4 kV alternating voltage (0.99 kV) is taken into consideration.

For several versions, the attainable service quality is computed applying a deterministic model based on outage data. Furthermore, the profitability of the respective network is assessed, taking into account customer and power density.

## RESERVE GRID TOPOLOGY

### MV Reserve Grid

The basic structure of the MV grid consists of two closed loops (average length 5 km), indicated by the blue lines in Figure 1. Each loop is fed from another substation. A substation feeds about ten loops; each loop feeds about 10 transformer substations.

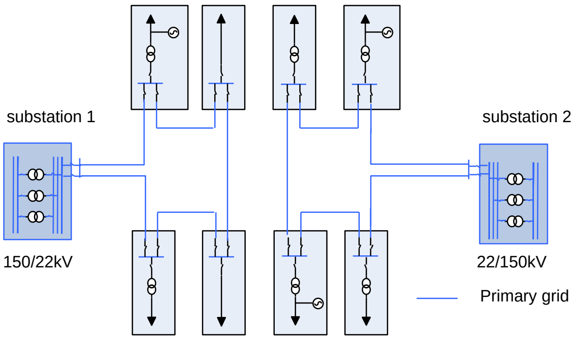

**Figure 1 Topology of a primary distribution grid on the medium voltage level.**

The concept of the reserve grid allows various topologies which affect the availability and security for the customers. The medium voltage reserve grid (MVRG) used in the pilot project, depicted in Figure 2, is indicated by red lines and denoted by MVRG A. It offers a maximal reserve power of 40 MVA (in case of symmetrical loads [1]) and a high availability and security.

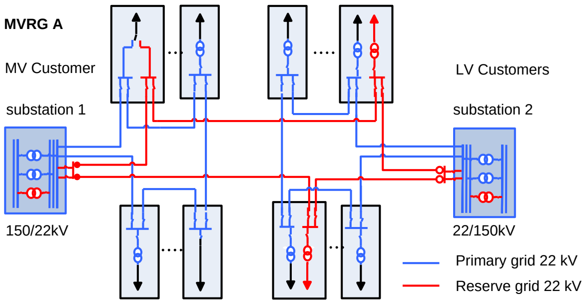

**Figure 2 Topology of the primary distribution grid on the medium voltage level including a reserve grid.**

Figure 3 shows alternative topologies which are simpler compared with MVRG A. They are more economical for the same required reserve power but less reliable. Both concepts use, instead of a ring shaped grid as applied in Figure 2, a radial feeder (Figure 3). The radial connection can be 40 % shorter or more than the ring shaped reserve grid and hence is a more economic solution. However, the reserve power is limited to maximal 20 MVA compared to the 40 MVA of MVRG A which means less customers can be connected to the reserve grid.
In the topology MVRG B in Figure 3, the transformer

substations are connected to the grid in the same way as in Figure 2 (MVRG A). In the more economic case on the right hand side (MVRG C) the customers are connected to the grid using either plug connections or electrical cubicles (MVRG C).

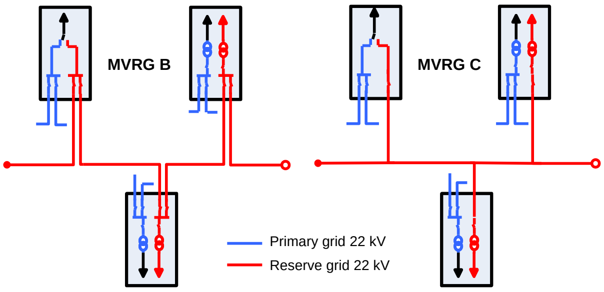

**Figure 3 Alternative MV reserve grid concepts**

## LV Reserve Grid

In the pilot project, each customer is connected with his own radial feeder to a transformer station (LVRG 1 in Figure 4). This is a common concept for large loads in standard low voltage grids. However, in areas with higher customer density, a radial feeder may have several house connections.

To connect more distant customers, one has the choice between following alternatives:

- Using a meshed LV reserve grid (LVRG 2 in Figure 4)
- Augmenting the LV voltage (0.99 kV) allowing for longer radial feeders (LVRG 3 in Figure 4)

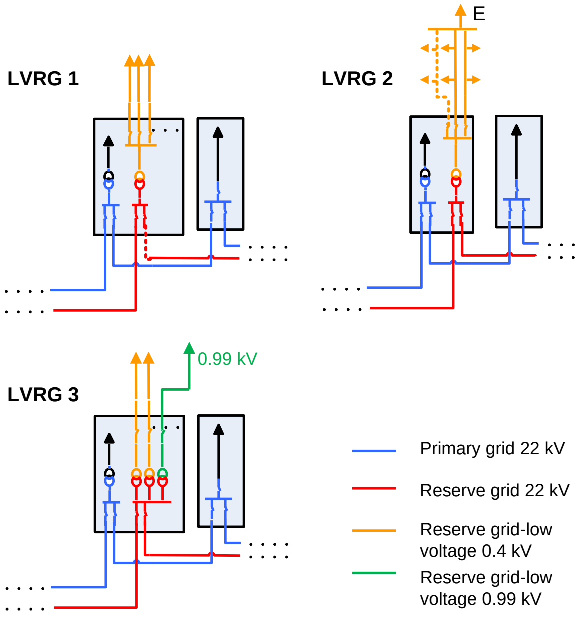

**Figure 4 Various LV reserve grid topologies**

In the following, various MV and LV topologies are analysed with respect to reliability and costs.

## RELIABILITY

The reliability results presented in this section are calculated by the same method already used in the previous paper [1]. The following indices are used:

| | |
|---|---|
| H | Outage rate in number per year (#/a) |
| T | Outage duration in minutes (min) |
| P | Outage probability in minutes per year (min/a) |

## MV Reserve Grid

Table 1 shows, in the first row, the difference in reliability for the connection to the primary network (Figure 1) and the three grid versions shown in Figure 2 and Figure 3. In case of an outage, the customer is connected to the reserve grid by an automatic switch (switching time 10 s) without buffering. Therefore, outage rates are in all cases almost the same (every 5 year an event). By contrast, the outage times differ significantly for customers without a connection to the reserve grid and customers with a connection: the outage time decreases from 82 min, in the case of a connection solely to the primary grid (Figure 1), to approximately 1.6 min, 2 min and 2.4 min for MVRG A, B and C connection, respectively.

The economic version MVRG C has a 50% higher outage probability as MVRG A but the 0.5 min/a is still a small value.

| | NZVA values | Primary grid (MV) | MVRG A | MVRG B | MVRG C |
|---|---|---|---|---|---|
| For MV | H(#/a) | 0.2159 | 0.2113 | 0.2113 | 0.2114 |
| Customer | T (min) | 82.3200 | 1.5960 | 1.9800 | 2.4120 |
| | P (min/a) | 17.7729 | 0.3372 | 0.4184 | 0.5099 |
| LV Grid | H(#/a) | 0.2220 | 0.2266 | 0.2266 | 0.2266 |
| Radial f. 0.4kV | T (min) | 93.0660 | 1.6260 | 1.9860 | 2.5620 |
| 200m | P (min/a) | 20.6607 | 0.3685 | 0.4500 | 0.5805 |

**Table 1 Reliability indices for MV and LV customer**

## LV Reserve Grid

To evaluate the reliability parameters for a LV customer, a standard situation is assumed which applies to every connection shown in Figure 4 with two exceptions:

- The customer E in LVRG 2
- The customer with the longer 0.99 kV radial feeder

Both have slightly different reliability indices because of different cable length and redundant supply path.

The standard customer is fed directly by a smaller 250 kVA transformer (LVRG 3, Figure 4) via a 200m radial feeder. Considering the security of supply, the customers in LVRG 1 have the same reliability values independent of the fact that they are fed by one bigger transformer (four customers, 1000 kVA transformer). The same applies to the smaller loads connected to one radial feeder (200 m) in LVRG 2.

The second section of Table 1 shows the results for a standard LV customer; with values 10% larger than the values in section one for medium voltage. Realistic modifications of grid topology (i.e. customer E in LVRG 2) and cable length change results marginally (last digit) and hence are not shown here.

The conclusion is that the topology (and protection scheme) of the higher-level MV network has more impact to the security of supply of a LV customer than the topology of the LV grid. This is the case when the LV grid is exclusively connected to one MV reserve grid. The situation may change when the LV grid has also redundant connections to MV grids fed by a third substation. Such possibilities are postponed to the further studies (in connection with distributed generation).

## COSTS AND CUSTOMER STRUCTURE

The development of a secondary grid requires initial investments by the system operator, which have to be passed on to customers. Depending on the chosen topology and thereby reliability, the costs for the secondary grid vary. Furthermore, the location of the secondary grid influences costs as the size of the supply area and related with it the number of customers and power density within a certain perimeter differ considerably between city centre and outskirts. In the following, it is discussed how the customer structure affects the costs of the secondary grid.

For a basic analysis, the investment costs for a secondary grid are regarded using estimate project costs. These can only be used to compare different grid topologies, i.e. versions, without implication to a future price structure of a secondary grid. Furthermore, it is assumed that construction costs are equal in city centre, districts and outskirts. The expenses of a self-contained reserve power supply with a diesel generator are taken as comparison value for a first assessment of the profitability [2]. For a current project, a study including operating costs, actual investment costs and expected revenues will be made before the investment decision is taken [3]. The investment costs of the secondary grid can be derived as:

$$K_{tot} = K_{res} + n \cdot k_{con} \quad \text{or}$$

$$k_{tot} = \frac{K_{tot}}{n} = \frac{K_{res}}{n} + k_{con} \quad \text{(cost per customer)}$$

with

$K_{tot}$: Total costs of secondary reserve grid and customer connections

$n$: Number of customers

$K_{res}$: Costs for the secondary reserve grid (independent of number of customers)

$k_{con}$: Individual costs per customer connection

Former investigations have shown that operating costs for a connection to a secondary grid are lower than for a self-contained power supply [1].

### MV Reserve Grid

In a first step, the MV reserve grid is regarded, assuming that the total required reserve power in a potential supply area is 20 MVA with 5-20 MV connections with the same required reserve power per customer and an equal local distribution. Table 2 shows the resulting cost ranges per kVA in relation to the average costs of a self-contained power supply by a diesel generator [2]. The reserve power per customer varies from 1- 4 MVA and the reserve power density is set to 13, 7 and 3 MVA/km$^2$ respectively.

| Area supplied | MVRG A $k_{res\ (20\ MVA)}$ in percent | MVRG B $k_{res\ (20\ MVA)}$ in percent | MVRG C $k_{res\ (20\ MVA)}$ in percent |
|---|---|---|---|
| City Centre | 75 - 110 | 50 - 120 | 45 - 90 |
| Districts | 95 - 135 | 65 - 145 | 55 - 110 |
| Outskirts | 125 - 170 | 85 - 195 | 70 - 135 |

**Table 2 Normalized costs for the MV reserve grid incl. MV connections**

It is evident from Table 2 that not only the reserve power density but also the reserve power required per customer and thus the number of connections has a strong impact on costs. More connections lead to a greater cable length, which can be identified as major cost factor.

MVRG A with the best reliability is the most expensive version to serve a reserve power of 20 MVA. Considering the maximum capacity of MVRG A of 40 MVA it becomes more cost efficient if a higher reserve power density is taken as a basis. MVRG B and MVRG C are fully utilized so that their efficiency cannot be further increased by connecting more customers.

MVRG C is the most cost efficient version, MVRG B gets less advantageous the more MV connections have to be planned. This is particularly unfavourable in the outskirts where the distances on the average are longer.

### LV Reserve Grid

Customers with lower power capacity are generally connected to the LV level as the costs per kVA increase with lower capacity per connection. These considerations can be transferred to the secondary grid. A LV connection to the secondary grid can be realized in different topologies as shown in Figure 4. As to the LV connection the costs for the different configurations depend on the required reserve power and the distance to customer.

The following considerations are based upon a connection with radial feeders as shown in Figure 4. Table 3 displays the cost ranges per kVA for a reserve power demand from 250-1'600 kVA per customer and a LV cable length from 50-250 m. The costs are normalized by the costs for a LV connection with 250 kVA and a cable length of 50 m. For the transformer, a capacity of 1'600 kVA and 1'000 kVA is chosen, for smaller units a multi-feeder solution is selected, which is evidently favourable.

| Reserve Power Demand in kVA | Feeders | LV Grid Radial f. 0.4 kV $k_{con}$ in percent |
|---|---|---|
| 250 | 4 | 100 - 495 |
| 400 | 4 | 70 - 315 |
| 530 | 3 | 60 - 245 |
| 800 | 2 | 55 - 180 |
| 1'000 | 1 | 70 - 170 |
| 1'600 | 1 | 50 - 110 |

**Table 3 Normalized costs for LV connections**

Table 3 shows again that the distance to customer and thus the cable length is the major cost factor, when multi-feeder solutions are regarded. For LV connections which exceed the supply radius of the 0.4 kV grid other versions as a 0.99 kV connection or a ring-feeder structure as shown in Figure 4 can be optimal and have to be studied individually.

With a simplifying assumption, the costs of a LV connection are added to the costs of the MV secondary grid. Table 4 shows the resulting cost ranges for the LV level, which is again displayed in relation to the costs of a self-contained power supply.

| Area supplied | MVRG A & LV Grid Radial f. $k_{tot\ (20\ MVA)}$ in percent | MVRG B & LV Grid Radial f. $k_{tot\ (20\ MVA)}$ in percent | MVRG C & LV Grid Radial f. $k_{tot\ (20\ MVA)}$ in percent |
|---|---|---|---|
| City Centre | 95 - 305 | 70 - 310 | 65 - 280 |
| Districts | 115 - 330 | 85 - 340 | 75 - 300 |
| Outskirts | 145 - 365 | 100 - 385 | 85 - 330 |

**Table 4 Normalized costs for the MV and LV reserve grid including LV connections**

The costs per kVA depend again on the specific customer structure to be served i.e. the area supplied. The costs decrease with higher power density, larger reserve power demand per customer and shorter distances to customer.

## CONCLUSIONS

In this paper, the concept of the reserve grid has been further discussed. Various possible topologies on the medium and low voltage level have been analysed considering technical and economic aspects. A reserve grid decreases the outage probability considerably because of the reduced outage duration. The highest reliability is obtained applying a ring shaped topology (MVRG A). The implementation of a secondary grid is particularly competitive for high reserve power density and high reserve power requirements per customer as the cable length is a major cost factor, but it can also be favourable in other locations depending on the specific customer structure particularly thinking of customer clusters in commercial areas or industrial estates. As already pointed out for an actual project a study will be undertaken, which includes these aspects as well as actual investment costs, operating costs and expected revenues.

In future studies, the reserve grid will by extended by distributed generation consisting of renewables and diesel generators. This version of the reserve grid offers a power supply during an outage in the transmission grid. The investigations will focus on the reliability [4] of the reserve grid in isolated operation.

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