INTERCONNECTED LOW VOLTAGE GRID, GRID FOR THE FUTURE SMART GRIDS?

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ABSTRACT

Low voltage (LV) grid is mostly operated as an open ring or radial network and this paper analyses interconnected grid topologies, which bring higher reliability, higher voltage stability and lower losses. Unfortunately, interconnected grid topologies are believed to be much more expensive than traditional topologies and their operation is much more complicated. On contrary, meshed or at least more interconnected grids should represent an important part of future smart grids. Thus, it is necessary to deal with this topic and to start a serious discussion about pros and cons of this conception. This is the goal of this paper, whose main benefit is an idea, how to redesign existing grid, where it is advantageous, because it is not possible to expect that Distribution System Operator (DSO) will have enough time and money to do this within standard grid renewal. Lifetime of the low voltage grid is way beyond the time horizon, when the solution has to be ready. Hence, this paper shows benefits of interconnected grid topologies and it discusses ways, how it is possible to tackle the disadvantages of this topology. In this paper the situation in typical municipal areas are analyzed, because especially in the municipal network can be the advantages of meshed grid most beneficial.

INTRODUCTION

DSOs have to deal with many challenges these days, which may be often opposing. On the one hand DSO has to ensure secure, safe and reliable power supply, which satisfies requested power quality parameters, even with still increasing penetration of distributed and intermittent energy sources and slowly electric vehicles (EVs), as well [8]. These new trends and their integration into the electricity grid demand grid expansion or grid reinforcement in many cases. On the other hand the electricity business is full of uncertainties at the moment, which is often a reason for reduction of investments, even in distribution grid. Therefore, DSOs should try to question their planning and operations rules of the grid. Mostly on the low voltage level as many of these new challenges are most relevant there. Many studies have already shown that new technologies (often described as smart technologies) or their combination with business-as-usual approach could in fact lead to less expensive solution than conventional way, which is represented by grid expansion and reinforcement [3], [4]. Moreover, new solutions can help to achieve goals set by European Directives e.g. Energy Efficiency Directive. This paper intends to look at the topology of the low voltage grid, which can help to tackle many of these issues relevant for DSO. The potential of meshed topologies in increasing hosting capacity is a topic of many studies [2], [5], [7] and this paper intends to show further point of view.

As smart metering and power line communication is going to be an important part of future grids, this paper shortly discusses even possible consequences of redesign of the grid topology on the communication and synergies, as well.

This paper summarizes findings from a study of PREdistribuce, a.s. and EGC - EnerGoConsult CB s.r.o. PREdistribuce, a.s. is a distribution system operator on the licensed territory of the Capital City of Prague, Roztoky u Prahy and the municipality of Žalov in Czech Republic. It belongs to the PRE Group, which history dates to back to 1987. PREdistribuce, a.s. operates 110 kV, 22 kV and 0,4 kV grid with the total length almost 12 000 km with nearly 5000 stations and supplies more than 760 000 customers in total.

The firm EGC - EnerGoConsult CB s.r.o. was established in September 1997. The primary area of its activity is electric power engineering. The scope of activities ranges from design of specialized equipment, power quality and other measurements to software development, elaboration of studies or consultation. The firm also takes part on legislative and standardization process.

DESCRIPTION OF ANALYSED LOCALITIES

It is believed that meshed network is suitable especially for municipal network. From this point of view the analysis was focused on three typical localities that can be found in the city. Standard transformer station (DTS) in all analyses localities includes two medium voltage (MV) feeders and 8-10 LV feeders and one MV/LV transformer.

City centre / downtown area

This area consists mostly from shops, restaurants, office blocks and apartment buildings. City centre contains several historical parts of the city with narrow streets where any changes or operations are difficult. Average number of connection points per one secondary distribution station in this area is about 350-400 with average length of one LV feeder approximately 200 meters.

Apartment blocks area

Apartment blocks made of prefabricated concrete are very typical areas in cities in the Czech Republic. Typical attribute is concentrated number of households in relatively small and bounded area. Around 47 % of population of the city lives in these blocks of flats. There are about 550 households per one MV/LV transformer station with the LV feeder about 25% longer compared to the downtown area

Periphery of the city

This location is a typical uptown part of the city with low population density. Family houses prevail in this area. There is the biggest potential for growth in terms of new technologies (i.e. number of photovoltaics, EVs, heat pumps…). Average number of connection points for one MV/LV transformer station is about 200-250 with average length of LV feeder exceeding 500 meters.

ANALYSIS OF LOW VOLTAGE INTERCONNECTION POSSIBILITIES

The grid in above mentioned typical urban areas was analysed. Adding fuses in link boxes, where different feeders are ended but they are not connected together, enables varying degree of interconnection. This kind of interconnection could be reached in an easy and cheap way, i.e. standard low voltage fuse. However, with increasing degree of interconnection the complexity of system operation during a failure increases. These consequences can be solved in various ways, but it is beyond the scope of this article.

Weak couplings

Weak couplings have been considered in this analysis in link boxes which connect two different LV feeders together. Weak couplings are fuses with lower nominal value compared to the fuses at the feeder beginning i.e. in LV switchgear in distribution station.

Open ring

It is current status of analysed LV grid, where feeders are operated radially as an open ring. This means, in normal condition, that feeders are not interconnected to each other, but in case of maintenance or failure, feeders can be connected together to bypass the disconnected area or to be connected to a different source (another MV/LV transformer). Advantages are simplicity, selectivity (in terms of protections), transparency of the grid and easy easy maintenance. On contrary, disadvantages are among other uneven distribution of load in LV feeders, lower reliability, higher voltage drops along the feeder and higher losses.

Loop within 1 MV/LV transformer station

It is practically current grid topology, but LV feeders supplied from the same transformer are connected together using weak coupling. Main advantage is better load distribution and increase of voltage stability. In case of failure on LV level, the affected feeder is disconnected (same extent of the outage as in the radial grid due to the weak coupling).

Loop within 2 MV/LV transformer stations

Main advantage in this case is that a failure on MV level or in a MV/LV transformer is eliminated if these two MV/LV stations are supplied from different MV feeders. Also higher voltage stability and lower losses can be expected due to this interconnection

Interconnection among several MV/LV stations

It is the most complex but the most reliable system. In fact, it can be described as a meshed network. However, as it was formed from an open ring system, this grid is not so much meshed as classical meshed networks are. Nevertheless if the system is properly designed, it should cope with failures on MV, LV levels and on MV/LV transformers. There is an urgent need for periodic inspections of weak couplings, otherwise it may lead to the collapse of entire network one day, when more failures accumulate in the grid.

GRID RELIABILITY ON THE LOW VOLTAGE LEVEL

For purpose of this article the assumption that there are no failures on high voltage (HV) level affecting LV customers was made. Actually from time to time there are some failures that have impact on LV customers, but thanks to interconnection of HV networks, modern protection systems and remotely control switchgears is the impact on Standard Average Interruption Duration Index (SAIDI) and Standard Average Interruption Frequency Index (SAIFI) marginal. This hypothesis is proved by figures in table 1, which shows impact of failures on each voltage levels on SAIDI and SAIFI.

Failures/unplanned interruptions	SAIDI driven by failures	SAIFI driven by failures
LV level incl. MV/LV	35,3 %	14,3 %
MV level	63,2 %	78,6 %
HV level	1,5 %	7,1 %
Total influence of failures	100 %	100 %

Table 1: Overview of the impact of various voltage levels to SAIDI and SAIFI in urban network [1]

Another reason to omit HV failures within this paper is the fact that the potential failure on HV level has the same effect on LV level despite of different level of LV interconnection.

Impact of interconnection on reliability of supply

The impact of some failures on SAIDI and SAIFI may be reduced thanks to the interconnection on LV level as table 2 indicates. In this table 100 % means current state (i.e. no benefit of different grid topology) and 0 % means that all effects of the failure have been removed thanks to different grid topology (i.e. SAIDI/SAIFI were zero and if failure occurs, there are no impacts to the LV supply). It is assumed that in case of failure of MV/LV transformer, one transformer is able to supply customers connected to the second transformer (and the same for MV feeder), which does not have to be truth all time especially, when transformers are heavily loaded. One more crucial assumption for loop within 2 transformers and meshed grid has been made - MV feeders should be alternated properly to ensure supply to the grid when one MV feeder is disconnected. With increasing the number of transformer station within meshed grid, the validity of this assumptions rises. However, these points should be analysed in more detail and it is beyond the scope of this paper.

Grid topology	Failure of MV/LV transformer	Failure of LV feeder	Failure of MV feeder
Current state	100 %	100 %	100 %
Loop within 1 transformer station	100 %	100 %	100 %
Loop within 2 transformer stations	0 %	100 %	0 %
Interconnection among several transformer stations	0 %	100 %	0 %

Table 2: Impact of failures on differently interconnected LV grids [1]

Table 2 shows that due to interconnection on LV level it is possible to significantly reduce the impact of failures on MV and MV/LV level to continuity of supply on LV level.

Grid topology	SAIDI driven by failures	SAIFI driven by failures
Current state	100 %	100 %
Loop within 1 transformer station	100 %	100 %
Loop within 2 transformer stations	9,6 %	10,0 %
Interconnection among several transformer stations	9,6 %	10,0 %

Table 3: Final SAIDI/SAIFI driven by failures in different LV grid topologies [1]

Considering the impact of different types of failures in table 1, the total effect of interconnected networks on SAIDI/SAIFI driven entirely by failures on all voltage levels is shown in table 3.

VOLTAGE STABILLITY

One of the basic tasks for DSO is to ensure quality of supply prescribed in standard EN 50 160 Ed. 3, where one of the main parameter on LV level is compliance with 230 V +/- 10 % (for 95 % of 10-minutes intervals) [6]. For gaining quicker view it is possible to look at variations between maximum and minimum voltage. The lower the variance, the easier is to meet the above mentioned requirements. Therefore the impact of various degree of interconnection was analysed and results are shown in table 4. It is obvious that loop within one transformer station compared to the current state has lower impact than the other types of interconnection. (Table 4 states, that in suburb are the voltage variations even greater, but this is caused by specifications in chosen area and cannot be relevant for generalization of results).

Locality	Current state	Loop within 1 DTS	Loop within 2 DTS	Meshed grid
City center	5,5 %	5,5 %	5,8 %	4,8 %
Apartment blocks area	4,5 %	4,0 %	3,5 %	3,3 %
Periphery of the city	10,3 %	12,0 %	7,5 %	5,5 %

Table 4: Voltage **v**ariations between maximum and minimum values [1]

Interconnection of 2 transformer stations and especially interconnection of several transformer stations brings lower voltage variations, which is important due to the increasing number of decentralized energy generation (DER) and increased demands on maintaining voltage levels within specified range.

GRID LOSSES

Increasing degree of interconnection has positive impact on level of energy losses, which is described in table 5. As it can be seen, the higher the interconnection is, the lower the grid losses are. Also in meshed grid the no-load losses could be even lower if some of the transformers will be disconnected during periods with low demands. It would lead to increase of load losses and to find an optimal state under respecting of reliable grid operation is not part of this article.

Locality	Current state - radial [MWh/ year]	Loop within 1 DTS [MWh/ year]	Loop within 2 DTS [MWh/ year]	Meshed grid within [MWh/ year]
City center	74,9	74,4	70,3	62,3
Apartment blocks area	54,8	54,6	54,1	50,2
Periphery of the city	52,5	55,3	49,8	40,0

Table 5: Total grid losses in analyzed areas in MWh/year [1]

NEW TECHNOLOGIES

The distribution grid becomes smarter as new equipment like remote control and monitoring, automatic back-up, modern protection systems and so on are being installed. These new grid components can help to tackle many if not all disadvantages of meshed topologies. When talking about new technologies, smart metering has to be mentioned. Nowadays, DSOs are at least testing this technology and in many countries due to legislation the implementation has already started. One of the key issues, next to data privacy and cyber security, is communication infrastructure. There are many solutions on the market and DSOs that are looking for own infrastructure often rely on PowerLine Communication (PLC) or Broadband over PowerLine (BPL) communication. It should be noted that this technology can help to operate interconnected grids, if the system is able to trace and actively manage the track of the PLC/BPL signal to identify problematic parts of the grid or even failures and hence, help to investigate e.g. state of the weak coupling, which is very crucial issue of analyzed interconnected grid topologies. On contrary, meshed topologies can complicate the distribution and steering of the PLC/BPL signal, as more master stations are interconnected. This issue should be further analyzed.

CONCLUSIONS

With increasing penetration of distributed energy resources (DER), EVs, heat pumps and other new technologies the DSOs will have to find solutions how to integrate them into the distribution grid in the most convenient way, i.e. as for the technical as well as economical point of view. Meshed grid topologies can become an important part of the solution, as they can significantly contribute to expansion of hosting ability of the grid. This paper presents results from simulations in real networks of three typical municipal areas. The results show advantages of interconnected grid topologies with respect to voltage stability, grid losses and especially grid reliability, which is more and more important in these days. The interconnections have been made by adding of low voltage fuses into current grid topology (open ring), thus it is an inexpensive way, how to create it. However, there are many disadvantages of interconnected grid topologies, too. The most important issue is its behaviour during failures, especially with increasing level of DER penetration. These aspects have to be examined carefully. It has to be noted that there are other solutions like on-load tap changer (OLTC) transformers, line conditioners, remote control and many other, which could in the end be more suitable for increasing hosting ability of the grid or its reliability. The goal of this article was to point out and quantify benefits of interconnected grid topologies with mentioning disadvantages as well to contribute to the discussion, if the meshed grid are grids of future smart grids or not.

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