VISION OF THE FUTURE POWER SYSTEM – DISTRIBUTION NETWORK 2030

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ABSTRACT

This paper presents the results of the Finnish national "Technology Vision of the Future Distribution Network" project. The aim of the project was to create a technology vision of future distribution networks. Because the life span of networks is very long, a long term vision is very important for guiding network investments and technology development.

The project consisted of the following subprojects:

- *Analysis of the present state of the networks*
- *Creating scenarios of the future operating environment*
- *Study of existing and future solutions in foreign networks*
- *Scenarios of technological development and mapping of existing technological options*
- *Evaluation of alternative solutions*

The paper presents possible outlines for future networks. In the creating of the vision, too futuristic approaches were consciously avoided, so that it will be possible to plan a realistic path from current systems to future systems. The Vision, however, includes both existing technologies and technologies not yet available.

INTRODUCTION

Some of the most topical global challenges to electricity distribution in industrialised countries are increasing reliability requirements and ageing of networks. These challenges are valid also in Finland, where after years of focusing on issues relating to the deregulation of the electricity market, technical issues are now gaining increasing attention.

The regulator, Energy Market Authority, aims at keeping the prices of network services down while improving reliability. The network companies have realised that there are both reliability based as well as asset ageing based needs for a radical renovation of networks. This requires a long term vision of the future distribution network.

THE PRESENT STATE OF DISTRIBUTION NETWORKS IN FINLAND

Finland is a sparsely populated country with 2/3 of its area covered with forests. In spite of long line length per customer, the total price of electricity supply has been among the lowest in Europe. One of the reasons for cost effectiveness has been extensive use of simple overhead lines. At present 90% of Finnish medium voltage (MV) lines are overhead. On the other hand, overhead lines in forests are very vulnerable to falling trees. Most of the faults are caused by trees fallen on MV lines.

So far, reliability has been improved by increasing distribution automation, such as remote controlled disconnectors, numerical protection relays and network information systems with fault location capabilities. However, it seems that the reliability requirements are increasing more rapidly than these incremental improvements can provide.

At the same time, a massive number of wood poles are ageing. Many of the MV lines have been built during the 60'ies and 70'ies. Although the life span of wood poles has exceeded previous expectations, it is evitable that something has to be done to the millions of decaying poles.

CHANGES IN THE OPERATING ENVIRONMENT

In order to find out future requirements on networks, scenarios of the operating environment were created. In the following the key points of the most probable development are presented:

- The population in the rural areas is going to decrease and the concentration of the population is going to continue.
- The average electricity use will still be growing due to the growth of economy in Finland. During the past 15 years the average annual increase in GNP has been 3%, whereas the growth of electricity use has been 2.3%.
- Centralised electricity production is going to prevail while the proportion of distributed generation is increasing [1].
- The increasing dependence on electricity of the high-tech society brings higher supply reliability

requirements that can be satisfied by means of network reliability or by local backup. It is estimated that the per unit outage costs will be doubled by year 2030.

- Environmental issues, such as use of detrimental chemicals, EMF issues and aesthetical impact of the network will be emphasized.
- The global climate change will probably increase the occurrence of extreme weather conditions; high winds, rain and snowfall. This increases difficult conditions for overhead lines.
- The regulatory environment includes a lot of uncertainty, but most likely the reliability aspect will be more important than today.

FOREIGN TRENDS AND EXISTING SOLUTIONS

In order to find out global trends, possible solutions and visions, foreign networks were studied by literature studies and excursions. Around the world there are several R&D activities going on relating to the future technologies for power distribution. Generally two major development trends can be seen. One of them is the increased intelligence of the system and its components. In practice intelligence means, e.g., intelligent and communicating components [2]. Another is the tendency towards underground networks that are less vulnerable to weather effects. E.g. in Sweden many network companies are cabling their distribution networks. One of the lessons Finland could learn from other countries is the use of multiple protection zones in MV networks, in order to minimize the consequences of a single fault.

REQUIREMENTS FOR FUTURE NETWORKS

The following European requirements for future networks can be formed from the state-of-the art of networks and from the future scenarios:

1) The reliability should be remarkably higher than today. This means both lower average interruption duration and lower vulnerability to exceptional conditions, such as storms. In urban networks, the goal can be a distribution network practically without any customer outages.
2) Networks of the future have to be cost effective. Life cycle cost based thinking and the rise of labour costs will make networks with little need of maintenance more attractive.
3) Environmental aspects have to be taken into account carefully.
4) The networks should be flexible enough so that the changes due to, e.g., distributed generation or changes in the load can be handled with little effort.

TECHNOLOGICAL OPTIONS AND POSSIBLE NEW SOLUTIONS

Type of the approach

In this project, one of the most essential goals was to find technological options for future networks. Evaluation of foreign visions and their implementation revealed that often too futuristic visions tend to remain too distant, so that near-term steps are difficult to find. This is why a feet-on-the-ground approach relying mostly on technology currently available was chosen instead of focusing on new solutions. [3]

However, some technological options that are currently not yet available were included in the technology toolbox of the future. Because of different environmental and load density conditions there has to be a variety of tools. Optimal total solution can most likely be found using a combination of different technologies.

Technological options

In the following some of the most attracting technological options for future networks are discussed.

Cabling

In order to prevent major disturbances caused by extreme weather conditions, turning overhead networks into underground cable networks is the principal solution. Current price difference between overhead lines and underground cables is in Finland rather high but cost comparisons to the neighboring countries indicate that cable installation technology can be developed to narrow the price gap.

On the other hand, in the Nordic Countries there are regions of rocky soil where underground cabling is very difficult. Thus overhead lines will be needed also in the future.

Increasing the number of HV/MV substations and using light HV lines

Traditionally the protection of Finnish MV networks is concentrated in the HV/MV substations. The only circuit breaker on each feeder is in the substation. This means that every fault on the feeder affects all the customers of that feeder. Increasing the number of substations by using a simplified HV/MV substation structure is a very effective way to reduce the affected area and thus the consequences of a single fault. Simplified substations that have been introduced in Finland during recent years cost only ca. 50% of traditional substations.

One of the new approaches applied with the simplified substations is that they are usually placed underneath the existing HV lines thus reducing to need to build new HV lines. If this is not possible a light HV line structure can be applied. The estimated cost of the new type of HV overhead line is estimated to be 40% lower than in traditional solutions.

Increasing the number of circuit breakers or remote controlled switches

Remote controlled disconnectors have been used since late 70'ies, and they have proven to be a very efficient way to disconnect the faulted part of the feeder. In order to save the healthy part of the feeder from experiencing even a momentary fault, circuit breakers should be used. They can be line breakers (longitudinal) or light lateral (branch) breakers. These breakers can be equipped with fast telecommunication, often utilizing wireless technology.

Line siting

Siting lines along the roads has been recommended already a long time, but there are still many lines in the forest. While re-siting the lines, also the structure can be re-thought. If undergrounding is not feasible, overhead cable or covered conductors are often superior to traditional overhead line with bare conductors.

1000 V distribution

1000 V distribution is a promising new technology for public distribution networks. By using this technology many vulnerable MV branches can be replaced by 1000 V lines forming their own protection zone. Additionally, instead of bare conductors, aerial bundled conductors can be used. Depending on the soil, cable ploughing may be used as well. Technical and economical studies have shown that 1000V technology is beneficial, if the load of the branch line is less than 60..100kW and the distance is between 1..5km [4].

Compensation of earth-fault current

Increased cabling increases capacitive earth-fault current. It may be necessary to change neutral point treatment. One of the benefits of compensated network compared to network with isolated neutral is that many of the faults will extinguish without breaker operations. Avoiding of even momentary interruptions has become important because of sensitive loads. According to practical experience, self-extinguishing is especially likely if the secondary substations are equipped with surge arresters instead of spark gaps.

Distribution automation

Modern network information systems include option for distribution management applications. Control room automation helps operator in minimizing both planned and unplanned interruptions. By means of fault location techniques based on numerical relays or fault indicators, outage times can significantly be reduced. Traditionally distribution automation has been applied mostly in rural networks, but analysis has shown that automation is economically justified also in urban networks.

The key technical functions of distribution automation are remote controlled line switches, fault indicators, and fault distance computation based on relay measurements.

Microgrids

A future option for increasing reliability and utilizing distributed generation are microgrids, that is, parts of distribution network containing distributed generation and suitable to island operation. At present, microgrids are still in research phase.

Power electronics in electricity distribution

The next revolutionary step in electricity distribution may be power electronics. By means of power electronics, DC distribution is possible. DC distribution has many benefits compared to AC distribution:

- Use of higher voltage (still LV) is possible, which enables higher power to be transmitted.
- Some MV branches can be replaced by DC branches. DC branches are separate protection zones, improving distribution reliability.
- Voltage problems at the end user can be mitigated, if the end user voltage level is controlled by an inverter.
- Higher voltage drop in LV lines can be permitted, which makes dimensioning of the conductors easier.
- Connection of many types of DG units is easier.

On the other hand, DC distribution requires installation of inverters at both ends of the DC section. Increased number of devices may increase the risk of component failure, and the harmonics level may be problematic. Another drawback in that power electronic devices have shorter life span compared with traditional primary network components.

THE VISION OF FUTURE NETWORKS

The vision of future networks fulfils the aforementioned requirements of reliability, cost effectiveness, environmental friendliness and flexibility. These can be achieved by using a large variety of technologies. In the following the vision is divided into a rural and an urban perspective.

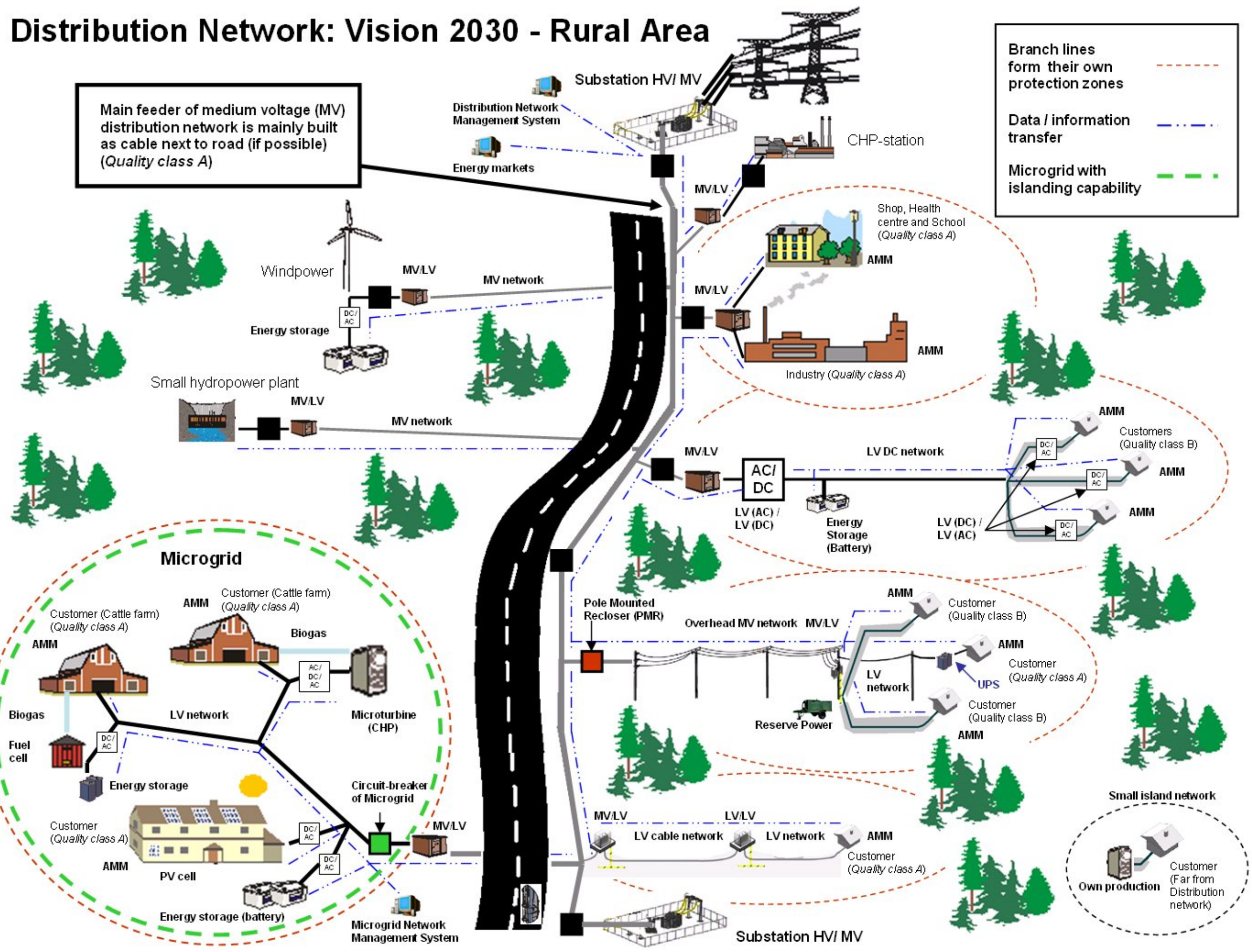

Figure 1. The vision of future rural network.

The vision of rural networks

The vision of future rural distribution network is illustrated in Figure 1 (above). In rural networks the vision includes reliable main feeder, often underground construction, and many of the lateral branches form their own protection zones. The number of circuit breakers will be higher than today. Technologies like 1000V, DC distribution, and distributed generation will be applied. Along with the electricity distribution, there will be an extensive communication network utilized by the electricity distribution network automation.

The vision of urban networks

The vision for urban areas is a disturbance-free, invisible distribution network. The reliability is enhanced by distribution automation and guaranteed to critical customers by local backup systems. Invisibility means total undergrounding and integration into other infrastructure.

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