THE FUTURE SUBSTATION – REFLECTION ABOUT DESIGN

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ABSTRACT
In order to establish a base for the Vattenfall Group R&D-activities within the substation area a study with the aim to create a vision of the future regional substation has been conducted. A great number of group specialists from different countries have been involved in the innovative work to ensure that the design fulfil future requirements from customers, authorities and owner. Substations using power electronics has in long-term been found most suitable to meet relevant demands. Solid-state equipment is foreseen for most applications, such as transforming, converting, rectifying, voltage regulation, balancing and breaking. The work has also resulted in identification of short-term development, including advanced insulation coordination and suggestions for switchgear configurations.

INTRODUCTION
Many of the Swedish regional substations are now about fifty years old and soon in need of replacement. To have the most suitable performance the design of future substations has been studied. The purpose is to create a vision of a regional substation within Vattenfall networks, with highest voltages between 52 kV and 170 kV, that can fulfil present and coming technical, economical and environmental demands. The results of the study can be the basis for future investments in regional substations. Vattenfall is Europe's fifth largest generator of electricity and the largest generator of heat. Our vision is to be a leading European energy company. Vattenfall has about 33000 employees and is a Swedish state owned company.

METHOD
The result of the study is based on experience in distribution companies within the entire Vattenfall Group. Demands from customers, power system, owner, operation and maintenance organisation, authorities, environment and public opinion have been accounted. Information has been collected through workshops and discussions within the Vattenfall Group and with universities and technical institutes. During the study the concept has also been discussed with manufacturers to make development possible. Relevant technical reports and papers have been studied. The collected information has been subedited and analysed, resulting in a vision for a future regional substation in the year 2030.

A VISION FOR A SUBSTATION YEAR 2030
The main features for a future substation are high reliability, simplicity, modularization, intelligence and low environmental impact. In this paper these and other features for a substation of today and of tomorrow are concluded, drivers and needs are discussed.

By using power electronics, combined functionalities can be foreseen which reduce the cost and increase the reliability. A description over required functions has been developed.

Station layout and design
Two main drivers for Vattenfall are customer satisfaction and environment protection. High availability in power supply and good power quality are required for future satisfaction of the customers. It will be essential to understand the customer needs and to increase the reliability.

Lack of land will demand an effective land usage. Therefore a modular compact structure of the substation is necessary. In urban or in environmentally bad affected areas the future substation will be installed indoor or underground. A solid-state substation may consist of equipment placed in containers. Indoor installations increase the reliability and provide better working facilities.

In the future it can be difficult to find the right competences of operating and maintenance staff, hence the simplicity of the station will be very important. The used technique must also be safe and simple to handle and be well documented.

Cables will be more common for connection between substations. Also position of the substation is simplified with cable connection. Cable connections are therefore generally foreseen. Real-time estimation and adaption in control and protection systems will be possible.

The change in load and load patterns will require a flexible substation. It must be able to take care of distributed generation and reversed transfer of power.
Reliability
New laws, taxes and regulations will put harder demands on the technical solutions in a future substation. If an interruption occurs it normally will lead to unnecessary payments and fees. In Sweden, a new law also state that risk and vulnerability analysis must be performed, and no interruptions longer than 24 hours are allowed after the year 2011.

As the vision for a substation in the year 2030 foresee common use of power electronics, the failure rates of possible power electronic components have been listed, and a reliability calculation assessment method has been suggested by STRI AB. STRI AB is an independent technology consulting company and accredited high voltage laboratory located in Ludvika, Sweden. The next step is to state the future design for a solid-state substation and perform a complete reliability assessment of this new type of installation.

The future increased need of availability requires a self-healing station. Faulty components should be by-passed and possible to be replaced without interruptions. Component redundancy or possible phase redundancy is needed.

Environment
The future substation must have low environmental impact. A compact design is recommended. It shall produce as low noise as possible, and also be environmental friendly in terms of chemical aspects. Chemicals, oil and gases, shall be avoided. Low electro magnetic field (emf) generation is a base for the design.

Economy
The price on distribution and transmission must be as low as possible, resulting in a demand for a cost effective substation. The need and costs for maintenance are predicted to decrease, as well as the total investment costs. This can be achieved by adapting simple solutions, which make it easy to install and maintain the substation. The maintenance shall be as low as possible i.e. the installation shall be maintenance free. In order to reduce costs, alternatives to metal should be considered. Composite may be an alternative. The used material must have a reasonable cost impact.

Protection and control system
The future substation with its more sophisticated and common functions needs facilities for better control and analysis.

There will be an increased demand on fast detection and disconnection of faults. Faults should be attended to before outage occur. This can be done by redundancy. Connection between substations via fibre optic makes analytical redundancy in protection system possible.

Integrated computerized protection and control equipment with new functions will be developed. The configuration of substations and the protections are automatically adapted to the relevant network configuration for optimal fault clearance and system control. Disturbance recording is included.

The system will be fully computerised. The computer will contain the gateway to the remote control centre (RTU), control functions, protections, measuring functions and condition monitoring functions. Redundant computers are necessary.

All communication with the primary equipment is done via a single process bus. This will be an optical fibre link. The utilisation of optical fibres avoids the problems caused by noise and surges from the primary equipment. A substation bus is used for the communication between the substation computer and the object units. The communications within the substation and between substations are according to relevant IEC standards.

Advantages and disadvantages
Substations using power electronics has in long-term been found most suitable to meet relevant demands. Some of the advantages with using power electronics in distribution networks have been indentified, such as:
- Rapid control of both active and reactive power giving a high level of power quality.
- Modular construction.
- Pre-assembled enclosures, which reduce civil work, installation and commissioning times.
- Reduction of environmental impact.
- Reduced overall project costs.

During the work, identification of possible disadvantages has also been done, for example:
- Initially increased investment costs.
- Need of new and improved maintenance and replacement programmes.
- Uncertain new technology.
- Need of new adaptive control and protection programmes.

Application of vision
The vision is presented for different manufacturers. Future items for development will be identified and a possible design of a future regional substation developed. Vattenfall will not directly take part in development of new equipment, as the primary trade is power generation and distribution, but Vattenfall will be a counterpart as active adviser in manufacturers development, and also open for test installations.
SHORT-TERM SUBSTATION DEVELOPMENT

At the workshops also short-term substation development was identified. By advanced insulation co-ordination switchgears for lower BIL can be used at higher voltage level [1]. Verifying studies have been performed and development has started.

Of environmental reasons insulating oil and gases should be avoided. Vattenfall has a policy to reduce the use of SF6. Alternatives ought to be developed and used also for higher voltages. Dry transformers and vacuum technique as breaking media is suggested.

A reliability and cost study of different 52-170 kV substation configurations has been performed. In all configurations disconnecting circuit breakers are used, as nowadays practice in Sweden. The result of the study is that simplified H-configuration or bus-ring is recommended [2].

Insulation coordination

Studies at STRI, on behalf of Vattenfall, have shown that using well-designed protection by surge arresters can decrease the insulation level of switchgears [1]. The reduced insulation level offers the opportunity to make the switchgears even more compact than today and sometimes use present designs for higher system voltages.

Sometimes the system voltage is uneven from common standard levels. For example, in the Swedish 40 kV net, the highest voltage of equipment is 52 kV (BIL 250 kV). The international market for this equipment is small, but there is a considerable market for equipment made for 36 kV (BIL 170 kV) and 40,5 kV (BIL 185 kV). Therefore it is of interest that this type of equipment can be used in the Swedish 40 kV net.

In beginning of 1990th, STRI performed insulation coordination studies for compact substation designs for voltages up to 145 kV. The conclusion was that there are good margins to reduce all insulation levels by at least one step. Decision of how far to go may be based on economical conditions and possibilities to make suppliers interested in the concepts. In 2005 STRI performed a more detailed insulation coordination study for the 40 kV net.

Today metal-clad switchgears for 52 kV are filled with SF6-gas. The gas is a greenhouse gas and unfriendly to environment. The Vattenfall policy is therefore to reduce the use of SF6 when possible.

Air-insulated 52 kV switchgear for indoor installation are not available on the market. Existing switchgears for 36 kV or 40,5 kV should be possible to use in Vattenfall’s 40 kV network after completion with selected surge arresters [1].

The reduction of installation costs by using this new type of switchgear is estimated to at least 150 kEuro per installation compared to outdoor switchgear and 300 kEuro compared to GIS equipment, depending of substation configuration [3].

Pilot installations are decided and specifications for purchasing are prepared. Development of switchgear is intended to be included in delivery. Two pilot installations in the west of Sweden are planned for commissioning during 2009 – 2010.

Switchgear configurations

In Sweden the regional transmission systems (145 and 82,5 kV) are meshed and the regional distribution systems (52 and 24 kV) are normally operated radial. In urban areas the regional distribution systems have interconnections that are normally open.

Simplified substation configurations are made possible by the introduction of the new switching devices without decreasing the reliability of the substations. In order to select the most appropriate configurations for future substations, a reliability and cost study of possible future switchgear configurations has been carried out by STRI AB on behalf of Vattenfall.

The scope of the study in ref [2] is the reliability properties of typical 40 kV and 70-130 kV substations equipped with two power transformers and connected to the surrounding network by two overhead lines. Four different switchgear configurations were studied at each voltage level, based on encapsulated switchgear at 40 kV and disconnecting circuit breakers at 70-130 kV, see Figure 1.

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Based on the reliability study results, it is recommended to use configuration number 1 in Figure 1 to obtain the highest overall availability of future 40 kV and 70-130 kV substations [2]. Configuration number 1 also provides the highest flexibility with regard to scheduled maintenance of the circuit breakers. When also the economical aspects are considered, configuration number 4 provides an attractive alternative, especially when a very compact solution is required. The substation configuration should always be adapted to local conditions and be as simple as possible for relevant conditions.

CONCLUSIONS

By applying the method above, Vattenfall has created an innovative long-term vision for regional substations and identified objects for short-term development.

Based on the results from the workshops within the Vattenfall Group, the following main features have been stated for a future regional station:

- Simple, safe and reliable.
- With low environmental impact, compact and flexible.
- Intelligent, maintenance-free and self-reparatory.
- Cost effective.

Substations using power electronics has in long-term been found most suitable to meet relevant demands. Solid-state equipment is foreseen for most applications, such as transforming, converting, rectifying, voltage regulation, balancing and breaking. Common functions are foreseen. Power electronics reduce the need of space and provide compact installations.

In the short-term perspective it has been found that by decreasing the insulation level of switchgears, using well-designed protection by surge arresters, the installation costs can be extensively reduced.

Selecting the right configuration adapted to the local conditions can increase the substation reliability. Ring-diagram or reduced H-diagram with disconnecting circuit breakers is recommended.

DISCUSSION

The created vision for a substation 2030 will be the basis for further discussions with manufacturers and universities in order to develop new innovative equipment. When possible, common project groups will be started both with manufacturers and universities. This long sight view and the results from the development will make it possible to optimize future investments within the substation technology. Vattenfall has done this type of R&D-activities with great experiences in the past, and by performing this type of projects it is possible for network companies to challenge the manufacturers to develop new innovative solutions.

REFERENCES

