NEW CRITERIA FOR INSULATED SUBSTATIONS IN RURAL AREAS IN MEDIUM VOLTAGE CABLE NETWORKS IN SWEDEN

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ABSTRACT
This paper describes the new design criteria and the changes Vattenfall Nordic Distribution has carried out during purchasing and installing transformer stations in Sweden and Finland in the autumn of 2007. A new approach concerning the design, construction and demand of the transformer stations including the Medium Voltage switchgear has been carried out. The following important criteria and their results are described:

INTRODUCTION AND BACKGROUND
For historical reasons medium voltage networks in areas with large forests are built as overhead line networks. Early 2000 extensive rebuilding of the 10-20 kV Medium Voltage network has started in order to improve the network reliability especially in the rural areas. Every year some parts of the Vattenfall network were struck by the autumn and winter storms, causing various damages in the overhead line equipment. The result of this disturbance could be an outage time from 1 to 3 days or sometimes even longer. Customers nowadays are demanding a much higher availability of electricity and the use of more advanced electrical equipment like computers etc. makes our society much more vulnerable for interruptions. Vattenfall decided to compensate customers for the outage time above 12 hours. This made it possible to make a financial calculation of the costs and profits when changing the network design to be more weather reliable with lower outage time. The existing situation could be changed because a new technology for insulating overhead lines was developed. This new method made it possible to replace old bare lines with a type of covered conductor lines. These types of insulated lines are called BLL. It is a cable with PE covering of natural insulation. The outer layer consists of UV-resistant HDPE. The most important of all the new developments were new methods how to install underground cables that resulted in significant lower building costs of the network. New methods like cable ploughing, cable trench backfilling excavators and rotary excavators combined with automatic cable laying radically reduce the costs for installing these underground cables. The principles for the rural cable network structure has been developed and published by the association of electricity distribution companies in Sweden, Swedenergy, in a technical recommendation [1].

Using a combination of these new technologies for underground cables and insulated overhead lines made it possible to rebuild the Swedish distribution network on a large scale with the same type of cables. Vattenfall made a preliminary study of all feeding lines from the secondary substations in the total Swedish network and prioritised these lines using the available statistics to detect the areas with the highest downtimes, largest loads and largest number of affected customers. For example in the centre of Sweden it resulted in a selection of 300 of the most effected lines. A further study was made of these lines one by one which initiated a large investment program for renewal.

During these just started activities the large storm Gudrun damaged the network tremendously in 2005, which influenced the already started investments in overhead lines. Also the insulated overhead lines were damaged.

The government also announced that all Swedish Medium Voltage lines in rural forest areas must be made weather
Fig. 3  Damage caused by Gudrun

proof before 2011, recommending to change them into underground cable networks where possible. At this moment Vattenfall realised what design of substations should be used in the future. Shall conventional overhead lines designs be used or not? A design that not has been changed during the last 30 years and sometimes was suffering from major expensive failures. A previous CIRED paper [2] “Improvement of the supply quality by introduction of a new concept for modularized distribution networks in rural areas of Sweden” describes a completely new building technique with components, compact stations, sectionalising and coupling modules. And of course the new double PE-sheathed cable construction is an important part in the total design. This new building technique is a further development of the rural area network structure recommendation from Swedenergy [1]. Because Vattenfall never purchased equipment including compact stations earlier, in 2006 a new purchasing group for transformer stations was created based on these new insights. The task of this new group of 5 people was to define a new specification for purchasing appr. 1500 transformer stations needed in the Vattenfall Eldistribution AB network in Sweden and Finland in 2007. This made it possible to apply modularized components in these networks.

The following important criteria and their results are described:

- Environmental friendly design, fully in accordance with the important Vattenfall policy that SF₆ gas is not accepted if alternative technical solutions are available.
- Safe for personnel and also for unauthorized persons. Always safe to touch and a clear position indication for breakers and disconnectors.
- A technical design based on a very high level of safety.
- Real minimum maintenance for all components including the housing.
- The secondary substations designed with priority on operation and working environments.
- Fully modular components used in the total distribution network.

To achieve this, Vattenfall aims to use fully insulated switchgears and stations. Agreements were signed with 4 secondary substation suppliers in Sweden covering the demand for 2 years. This agreement is valid for delivery of 12-24kV substations in sheet steel or concrete design for the Vattenfall network, aiming on the use of fully insulated switchgear and station solutions.

ENVIRONMENTAL FRIENDLY DESIGN

Most compact Medium Voltage switchgear designs are based on SF6 gas insulation. Because of the Vattenfall environmental regulations SF6 gas is not accepted as an insulation material in Medium Voltage switchgear. This decision has a major influence on the purchasing negotiations and it limits the choice of switchgear manufacturers. Fully epoxy resin insulated 12 and 24 kV switchgear has therefore been selected as an alternative for the gas-insulated designs. Using fully epoxy-insulated switchgear with vacuum interrupters eliminates the environmental unfriendly leakage of greenhouse gasses into the atmosphere. For 12kV networks the Magnefix switchgear is selected as standard, in secondary substations with remote control the Xiria switchgear is used. At 24kV is the standard to use Xiria in the main part of the secondary substations. The epoxy resin insulated SVS switchgear is chosen as an alternative for distribution network to industries in rural areas. This type of switchgear is well known in the European market as well as in Sweden. Vattenfall has already a number of this switchgears in service.
There are many reasons to change over from air insulated to fully insulated switchgear:

- Minimum space needed for this type of switchgear.
- The transformer station size is smaller.
- In general there is less use of materials.
- It is easier to get a building permit for a smaller building.
- It is easier to integrate a smaller building in the area. Especially in existing urban areas it is very important to change the network into an underground cable network.
- Lower total operating costs.

SAFE FOR PERSONNEL AND ALSO FOR UNAUTHORIZED PERSONS

The new fully cast resin insulated switchgear is designed to offer full protection for the operator during cable access and manoeuvring. All connections to the SVS and Xiria switchgear are provided with touch-safe T-connectors. This is also the case in the different designs of compact stations without switchgear where the ring cables are directly connected to the transformer. The connection of the cables in the Magnefix switchgear is insulated with three different layers for personal protection. Vattenfall made the decision that no secondary substations should be delivered with porcelain insulators on the Medium Voltage connections. Instead the transformers are equipped with epoxy resin plug connections. (Type A according to EN50181).

The space for the transformer in a station has generally been a dangerous place to inspect.

A decision was also taken to insulate the whole low voltage connection inside the transformer room (degree IP20). This means that all the secondary compact substations and other secondary substations are fully insulated including al interconnections. The benefit of this among other things is that flashovers caused by dirt, moist, animals and vegetation are avoided completely. Until now this is yearly causing a number of interruptions in the network. Some unauthorized persons were killed breaking into a secondary substation to try to steal copper parts. Many stations are placed in green urban areas close to playing grounds with a risk that people are damaging and entering these stations. Entering a conventional air insulated secondary substation will cause a terrible accident that can be avoided by using a fully insulated design instead.

A TECHNICAL DESIGN BASED ON A VERY HIGH LEVEL OF SAFETY

The secondary substation shall be designed with a well-known and reliable technique. One demand told to all four suppliers is that all stations must be tested before delivery from the factory including a routine test protocol. When the units are provided with motor operation for remote control, they are always tested on site by the central Vattenfall network control room. The secondary substations should also be delivered with all necessary components needed for proper operation, like fuses, operating instructions and accessories. Secondary substations to a maximum of 315 kVA must be supplied with the proper main low voltage fuses also. The Xiria switchgear is equipped with an electronic protection relay (type WIC1) with a number of setting curves. One of the normally used curves is the fuse curve, which matches the Swedish fuse curve. When using the most common current transformers (16-56A) the lowest short circuit setting can be very low. (16 A). Compared with a primary fuse protection this relay has an extra feature, it can be set for overload protection also, starting with 14.4 A.[2]. For detecting ring cable earth faults in between stations a simple visual sign (a green or red light) outside each transformer station will be tested by Vattenfall in early 2009. The operator can see the signal from his car and he can directly go to the next station to find where the cable fault is located. Also in non-automated stations in rural area’s with relative long distances this is used as an inexpensive solution. This is realised with the IPS light system, connected to split-core current transformers mounted around the primary cables.

Changing from overhead lines to underground cables made a new approach for capacitive current compensation necessary. Due to this fact some of the stations are equipped with Petersen coils inside the transformer.
Real minimum maintenance for all components including the housing.

By rationalising the operation methods the maintenance costs should be minimised. This was a major issue during the purchasing process. All equipment should be designed as fully insulated switchgear on low- and medium voltage side, including the transformer connections. This will lead to a minimum level of maintenance regarding the protection against moist, dust, small animals and thistles. This is a major issue in older existing unprotected installations. The secondary compact substation is connected with insulated Elbow- and T-connectors and has no moving parts at all that must be maintained. The secondary substations with fully insulated switchgear has a maintenance interval of 15 years. Switchgear with relay protection for the transformer shall only be tested after 25 years. Checking the internal short circuit protection function of the protection relay can be done easy by using a small tester. Compared with a full functional relay test this test can be done very quickly. The housing of the station itself is built up with standardised modules made from galvanised and/or aluzinc steel elements, the foundation is also fully standardised and can be made of concrete or especially well treated aluzinc. The roof of the housing is also changed from a flat roof to an angled flat roof to ensure water drains away.

The secondary compact substations designed with priority on operation and working environments

All new designed secondary substations are more compact than the original versions. This is of high importance for getting building permits for instance in highly exploit archipelagos areas, easy handling on site during installing, inspection and operation. Almost all stations are outdoor operated which is in general more safe for the personnel. When operating under bad weather conditions is needed, a small additional cover can easily be placed to protect the operators. Because of the more compact secondary substations and switchgears it became more difficult to connect cables with larger diameters (>95 sq.mm). Together with the manufacturers of connectors and cable endings, Vattenfall has defined a solution for more easy cable connections with larger diameters by using a longer distance between the three-phase splitting point and the phase connectors including the earth screen. It is important that all personnel is properly trained to use this new technique, including the use of accessories for mounting the insulated elbow- and T-connectors, capacitive phase sequence testing, cable earthing, etc.

Fully modular components used in the total distribution network.

They complement each other in such a way that the technical solutions can be used for all existing and future different network structures. The different manufacturers of the compact secondary substations should have similar solutions. When there are delivery problems Vattenfall can easily purchase the stations from another supplier.

REFERENCES

[1] Svenska Elverksföreningen (Swedenergy) 1994, "Nätstruktur för landsbygden, jordkabel 12 och 24 kV"


[3] WIC1 operating manual TD_WIC1_01.08_GB