NEW DESIGN MEDIUM VOLTAGE SWITCHGEAR FOR WINDFARMS

M. Binnendijk, P.P. Leufkens
Holec Medium Voltage
P.O. box 32, 7550AA, Hengelo, The Netherlands
Tel: +31 74 246 9111, Fax: +31 74 246 4444, E-mail: info@holec.nl

W.B. Brizee, Th. Sneekes, R.W. Weber, R. Wiecherink
ENW
P.O. box 9111, 1800GC, Alkmaar, The Netherlands
Tel: +31 72 518 2838, Fax: +31 72 518 2173

SUMMARY

Electricity utilities have to adapt to fast political and legal changes. Wind energy plays the largest role in meeting to environmental targets. Windturbines have advanced fastly and are clustered nowadays into parks. To feed in the power existing 50/10kV stations have to be changed and new requirements are put to MV switchgear. The well experienced SVS/08 has been upgraded, making use of vacuum interrupter technology integrated in advanced epoxy moulding. This results in high reliability, compactness, user-friendliness, modularity and adaptation to diffuse existing (cable) situations.

1. INTRODUCTION: POLICY IN THE NETHERLANDS

Policy. Governmental policy in The Netherlands leads to rapid changes for the electricity utilities. Efficiency of power generation and distribution has been the first target. Many mergers of smaller electricity and gas utilities have been the consequence.
As a second step, the Dutch national government is focusing on liberalisation and free market of the sector. The number of monopolies should be brought down to a minimum. A new law has been issued leading to new structure of energy companies since the beginning of 1999. Large buyers of power (more then 10 Million kWh) are free to choose their supplier and a free trading energy market has been created in Amsterdam.

Environment. Environment is another target of public policy and energy companies.
In March 1997 the Dutch minister of Economic Affairs again issued targets of reduction of CO_2 - emission.
In 2000 3% of reduction should be established in comparison with 1995. This means for the Electricity Company ENW (province Noord Holland) that approximately 100MW has to be generated with wind energy.
Of course the application of renewable energy sources (also called "sustainables") has to be promoted and improved. Wind energy is the most important of them, others are: sun, disposal/biological, ambient heat and accumulation of energy.
One kiloWatthour of wind energy saves 0,57kg CO_2 with the application of firing fossil fuel in power plants as a reference.

Stimulation. Because of these policies and social responsibility the electricity companies have made energy pay-back agreements in order to stimulate private initiatives on wind energy. In addition, all companies got performance targets on their percentage of renewable energy, the so called "green label". ENW is willing to pay: 3.7 Eurocents for constant costs, plus 1.4 Regulating Energy Tax, plus 2.1 cts green label, amounting to 7.2 Eurocents per kWh. In addition the contract for back-supply has a term of 10 years in order to assure an investor that he can earn back his money. Another guarantee of a minimum time of availability is negotiated with the supplier of the turbine for at least 10 years, being 95 to 97% of the time.

2. WINDTURBINES AND WINDFARMS

Windturbines

The technical progress of windturbines has been considerable during the last fifteen years. Mid 80's units had a capacity of 50 to 75kW, solitary turbines since then went up to 250 and even to 600kW, a new step concerned clustering into windfarms of larger numbers of turbines. The windfarms nowadays have units of 500, 660, 750 or 1000kW, with hub heights of 50 to 60 meters and rotor blades of 25 meter length. The largest units are 1.6 MW and they can be placed offshore or on other places where the view is not spoiled e.g. large polders. The hub heights of these windturbines is 65 to 80 meter.
In Denmark units of 2 to 3 MW are in development with hub heights up to 80 meter.

For the time being, gearboxes are applied to asynchronous machines with a maximum slip, dependant on the wind, of approximately 1 to 1.5%. A soft starter is applied for the inrush. Figure 1 shows a sketch of the nacelle.

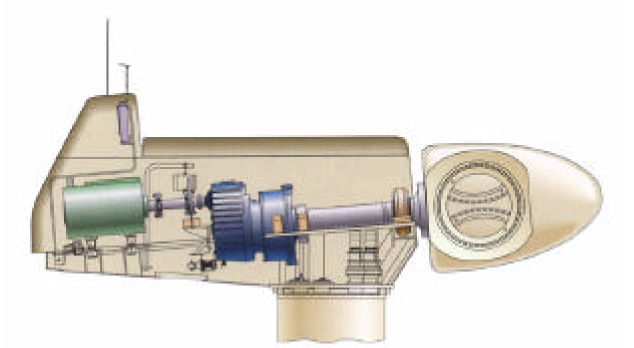

Figure 1: Nacelle of a 750kW windturbine with rotor, gearbox and asynchronous generator.

The transformer of 690V to 10 or 20kV is often placed next to the windturbine, sometimes it is placed in the tower or even in the nacelle. The blades are tuned at large wind velocities with the blade pitch control system in order to limit the power. The turbine is stopped at 25 m/s (10 at Beaufort's scale). In wintertime there is much more wind. Nowadays a period of service of 2.000 h/y is a good level, where this time is defined as the ratio between output and installed capacity. A demand for modern windturbines is that they can run autonomously and can be remotely monitored and controlled.

The cost price of wind energy depends on the turbine location and the method of financing. It varies with commercial exploitation (10 years depreciating term) from 6.5 Eurocents/kWh at places of heavy wind up to 9 cts at sites further from the shore, which is a disputable level for the decision of realisation. The investment of a complete windturbine including foundation, connection to the electrical grid and infrastructure can be roughly estimated to be 1.000 Euro/kW.

Windfarms

It is difficult to find the right location for windfarms because topics as noise, scenery and birds have to be taken into account. The accepted noise level is 40dB(A) at night at 7 m/s wind velocity. Special commissions decide on "horizon pollution". Birds which use to live in the neighbourhood of windfarms tend to learn surprisingly fast to avoid the danger. It is more difficult with migrating birds: in exceptional cases a windfarm is stopped half-yearly in order to let them pass. If preparation has been done well, permission to build a new windfarm is mostly given, but it can take a long time and the period is difficult to predict. In windfarms nowadays 5 to 15 turbines are placed. Windfarm 'Waardpolder', owned by ENW is presented in figure 2.

There are several parties involved in the property of windfarms: there is the owner of the transport grid (here: ENW), then there is a distribution company for the cable connection (in this case the former regional utility subsidiary), history plays an important role and last but not least there is the owner of the windfarm. This owner can be a private firm, but it can also be a commercial subsidiary of the electricity company (ENW Renewable Energy Ltd.) or a combination of both.
Every investor of course has to earn back his money. Outage costs money directly out of the pocket. Maintenance of turbines has to be restricted to a minimum, which will mean approximately half up to a whole day (e.g. for the gear box) twice a year. The maintenance of the 50/10kV transformer tap changer also causes outage time, with a duration of two days and a frequency depending on the type and the number of operations.

Figure 2: Windfarm 'Waardpolder' with state of the art windturbines.

3. CONSEQUENCES OF DISPERSED ENERGY FOR THE ELECTRICITY GRID

Solitary turbines were put at random places in former days, regularly at rural sites. Electrically they were coupled directly into the local distribution grid, often considerably downwards in the network. This gave rise to the following problems:

1) Maintaining of regular voltage can be difficult because of disturbance of compounding.
2) Energy transport suddenly can go into two directions, demanding:

- directional overcurrent protection to provide selectivity
- frequency protection to prevent running separately from the utility at net interruption
- under- voltage protection

3) The short-circuit withstand capacity of existing installations can be exceeded.

As capacities and power densities increased there was more demand for regulation by means of extension of the number of feeding-in locations. The following approach nowadays is applied: windturbines are clustered to

windfarms, which are uniquely connected by one or more 10kV cables to the feeder-installations.
They supply their energy to the local 50kV transport grid via 36MVA transformers. The structure is simple to overview in this way, but sometimes the grid in front presents a limitation because of the maximum 50kV cable capacity.
There is cos phi compensation up to 0.98 on the turbine feeding, in spite of the cable capacity.
All cables of installations in which back-supply takes place are being changed to the feeder installation in case of exceeding of short-circuit capacity. Older locations having a mix of existing feeding-in by means of (elder) wind turbines and changing and new built windfarms cause extra complications.

Situation in Noord Holland

In Noord Holland at the moment three transformer stations are being prepared for large scale back-supply by windfarms: Ulkesluis, Hoogwoud and Medemblik. In station Ulkesluis already three elder windfarms feed in with a sum of 15MW, a new windfarm feeding in 10MW is planned now. Figure 3 shows the single line diagram of the 50-10kV station.

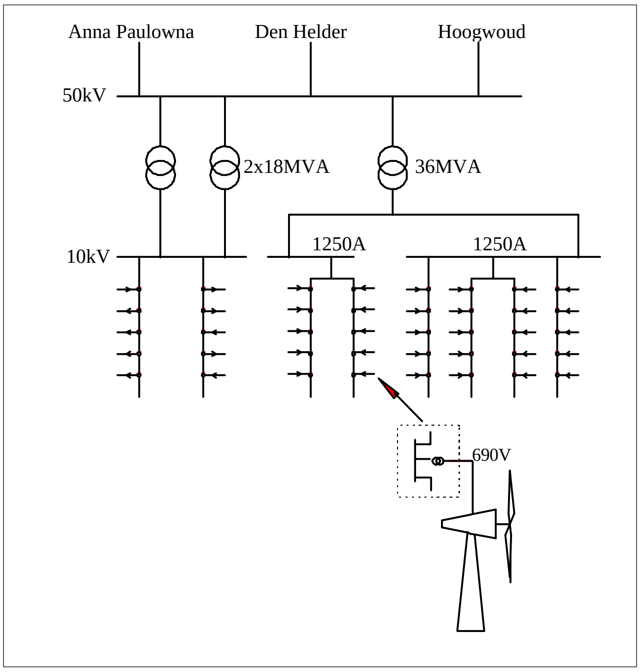

Figure 3: Single line diagram of 50kV - 10kV station 'Ulkesluis'

The two 18MVA transformers handle the 'normal' distribution. Only solitary wind-turbines feed back on these transformers. The 36MVA transformer is installed for feeding in four windfarms into the 50kV grid. Permission for a first windfarm feeding in 11,4MW into station Hoogwoud is given now, so cables can be installed.

KWh-Metering

Regarding kWh-metering it seems to be most logical to locate this on the 50kV side. However, this permits only having one proprietor to be connected. To install a special new purchasing station at the side of the windfarm is quite expensive. The kWh-metering was done per windturbine in the days that the supply was on the LV side.
Metering in the 10kV feeder panel in the 50/10kV station is nowadays mostly applicable. Cable losses are included then, which can amount up to 1.5%; the regional company is not willing to pay for this. Negotiations are taking place more and more: actually about green labelling, but in future about payment for back supply as well.

4. SPECIFICATIONS FOR SWITCHGEAR FROM THE APPLICATION IN THE GRID

The demand for subfeeder installations is increasing in Europe in general and The Netherlands in special. The trend is in the direction of larger energy-density and compactness. Holec decided to anticipate by developing the experienced Innovac SVS/08 to larger size.

The recognised demand of installations with busbars of nominal current of 1250A is as follows:
a) 630A - 20kA - CO sequence (cable connections)
b) 1250A - feeder for 630A outgoing panels - 20kA - CO
c) 1250A - 25kA - OCO (overhead line connections also).
The windfarm application is a good example of the application b), the single line diagram of the 10kV switchgear is shown in figure 4.

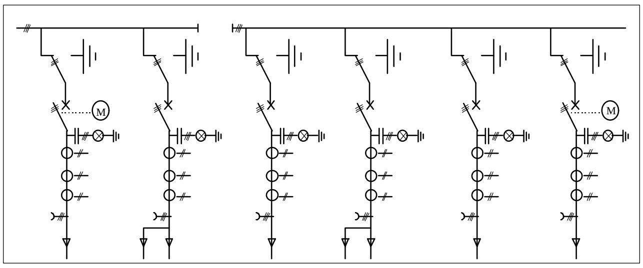

Figure 4: Single line diagram of the 10kV switchgear for supply from windfarms to the 50/10kV transformer in station 'Ulkesluis'.

The outer panels feed to the 36MVA transformer, the other four panels are fed by the four windfarms.
The following requirements come forward from the consumer point of view:
1. Reliable and free of maintenance.
2. Application for the 50kV stations of ENW.
3. Flexibility. Double busbar of 2500A would be likely, however is too expensive. If maintenance isn't necessary, this rate of flexibility is not important anymore. An optimum can be established applying two separate busbars of 1250A each.
4. Modularity. Usually installations including many 'spare panels' were planned for a long period of service.
   Nowadays financial optimisation is much more important and the legal regulations are hard to predict,

so it can be important to keep options open to change system lay-out and panel follow-up.

5. It is important to cope with many different kinds of cable, overhead lines and/or busbar-connections. This originates from history. Sometimes connections are required to:
   - existing distribution cables: PILC, XLPE single core, XLPE three core,
   - new distribution cables with elbows, straight plugs, cableshoe connections, large size, double connection,
   - easy accessible cable connections
6. kWh-Metering. High accuracy transformers are required, for some protection equipment as well. This requires multiple primary windings, which is larger and takes up more space.
7. Low impact on environment is in the Policy Statement of ENW.
8. Coping with existing Dutch 10kV grid-structure and protection philosophy.
9. It is policy of ENW to control stations in future remotely. The system will have to offer this option, although not foreseen in all situations, depending on costs/costsavings.
10. The role of automation will increase of course. Space and electromagnetic compatibility have to be taken into account.
11. All solutions have to shape an economical optimum for MV.

5. NEW RANGE INSULATION ENCLOSED MEDIUM VOLTAGE SWITCHGEAR

High quality switchgear for applications like for windfarms can be designed economically using integrated epoxy casting and vacuum interrupter technology. Especially the advanced moulding of large (up to 30kg) and complicated shapes with casted parts has contributed to this upgrading.

Insulation-enclosed switchgear

In fully insulated MV switchgear, each separate live part is insulated with cast resin. As epoxy resin eliminates the risk of flash-overs, internal fault tests are not mandatory. The epoxy resin is applied for construction and cooling as well. For further personnel safety a metal enclosure in addition to encapsulation of all live parts [1] is provided.
In addition to standard IEC60298, for metal enclosed switchgear, IEC60466 for insulation enclosed switchgear is applicable. According to these standards the installations have to be tested with power frequency withstand and impulse withstand voltage. Also leakage current and partial discharge have to be measured. Maximum safety is guaranteed by fulfilling these tests, which require amongst others sufficient thickness of the insulation.

Epoxy resin has been applied in different ranges of MV switchgear for more than 35 years. The resin is applied in switchgear having withdrawable oil circuit-breakers, which are not completely free of maintenance.
Vacuum circuit-breakers are applied more and more in MV switchgear since the seventies because of there excellent interruption behaviour [2]. Advantages are the fast recovery of dielectric strength after arc extinction, the very good insulating properties, the reliability and small dimensions. As vacuum interrupters have proved to be free of maintenance, withdrawable circuit-breakers are no longer necessary. Therefore modern types of switchgear with vacuum interrupters have fixed circuit-breakers. Reliability and safety increase when there can be no withdrawing of the circuit-breaker, as no locks are needed and there is no risk of misunderstandings and/or technical faults. Due to the integral design of all the components the switchgear has become more economical and compact.

The combination of the epoxy resin and the fixed vacuum technology has lead to the casting of the vacuum interrupter directly into the epoxy resin [3]. Mechanical stresses due to shrinking of the casting during the production process are eliminated by wrapping the interrupters with rubber sleeves before casting.

The optimal application of vacuum and casting technology is applied with commercial success since 1989 in MV switchgear type Innovac SVS/08 with ratings up to 24kV, 16kA and 17.5kV, 20kA with a nominal current of 630A (with 800A busbar).

Developing MV switchgear for higher ratings

Modern developing tools and the casting and vacuum technology were applied in order to upgrade the SVS/08 in to steps to a new SVS/12 range with additional features and higher ratings. The single line diagram and schematic cross-section are presented in figure 5.

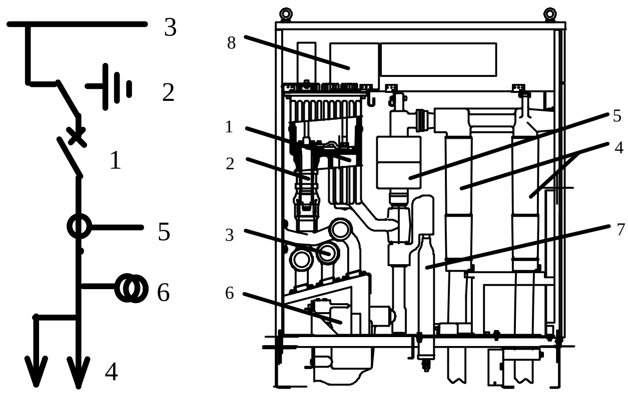

Figure 5: Single line diagram and cross-section of the SVS/12 switchgear.

1. Vacuum interrupter
2. Disconnector / earthing switch
3. Busbar
4. Cable connection
5. Current transformers
6. Voltage transformers
7. Surge arrestors
8. Driving mechanism

In the first project the busbar rating has been lifted to 1250A and the cabinets were enlarged. The extra space can be used for current transformers for kWh-metering and differential-protection applications or for the option of two cables/phase.
The instrument-box, wiring channels and cable connections were improved. Figures 6 and 7 show a panel with extended current transformer capability and the installed pilot project.

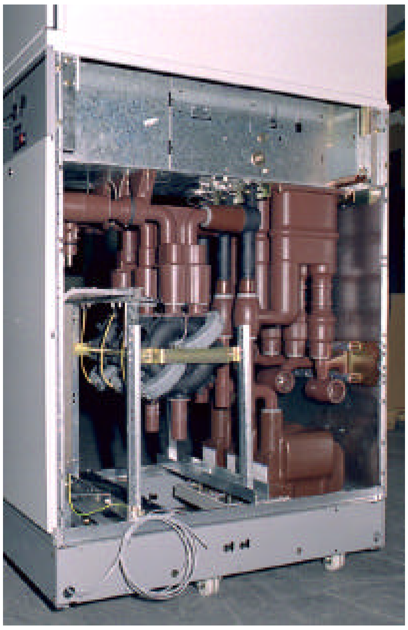

Figure 6: Innovac SVS/12 switchgear with large space for new features.

In the second development project all the nominal ratings have been increased from 24kV, 800A to 24kV, 1250A and the short-circuit withstand ratings to 24kV, 25kA with autoreclosing sequence. A photo is shown in figure 8.

Dielectric design. Dutch requirements on partial discharges used to be more severe then IEC. Attention is paid to minimise any voids in the castings. As the total encapsulation rules out any possible flash-over, the nominal voltage determines the mutual distance between live parts. Epoxy resin moulding offers freedom of choice in shapes applied for optimal field control and application of free air in stead of SF_6. Finite-element calculations are common nowadays to optimise dielectric design and to accelerate the development, resulting in compact and economical solutions.

Thermal design. Low losses and good cooling are required for high ratings in compact panels in order to limit temperature rise. Design of short routes of current, smart vacuum interrupters and sufficient conductor cross-section achieves low losses. Casted metal heat-conductors have been applied to diffuse the hot spots while casted cooling ribs have been provided to improve the heat convection. Practical implementation can be seen in figure 8. Radiation, the third cooling mechanism apart from conduction and convection, plays a significant role in the cooling as well.

Figure 7: First commercial SVS/12 project with 630A panels.

Short-circuit withstand. The MV switchgear has to be able to withstand and interrupt short-circuit currents. A new compact vacuum interrupter for 24kV, 25kA has been developed, suitable for being casted into epoxy resin. The operating mechanism applied is suitable for autoreclosing sequence for application in grids with overhead lines.
Lorentz forces during short-circuits in the order of 5kN/m are the consequence of compact design. In order to optimise the mechanical strength of the supports, 3D finite-element calculations are used, as can be seen in figure 9.

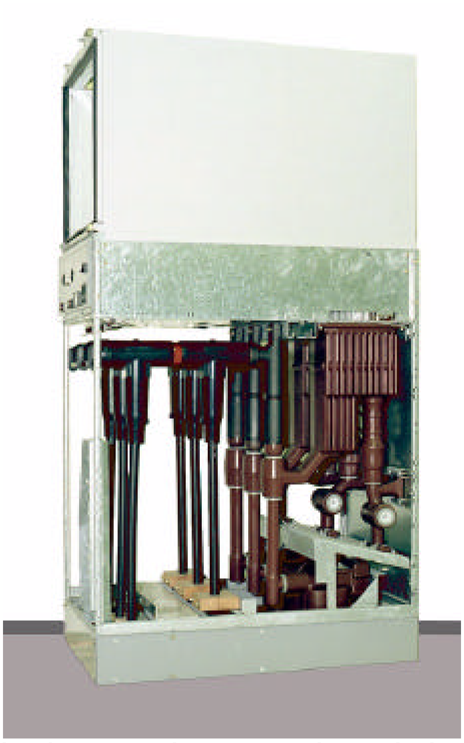

Figure 8: The 24kV, 1250A, 25kA SVS/12 switchgear in development.

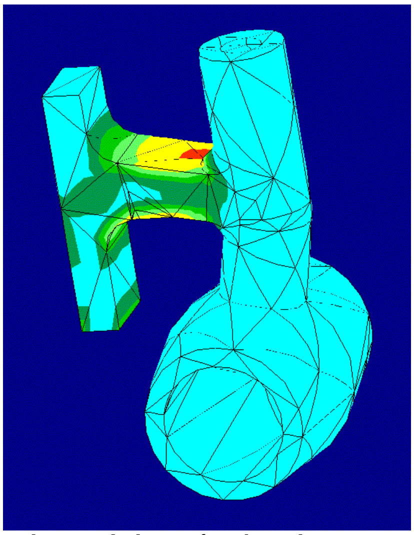

Figure 9: Finite-element calculation of mechanical stresses in epoxy resin busbar support.

Applications and accessories

Applications of the SVS/12 MV switchgear with ratings up to 24kV, 1250A, 25kA are in distribution grids and in industry. For users suitability for his applications, user friendliness and ergonomics are of great importance.

Modularity. The range consists of circuit-breaker, loadbreakswitch, busbar sectionizer, busbar-connection and measuring panels. The sequence of panels can be chosen randomly and existing installations can be extended easily.

Cables and earthing. On the locations of the windfarms the technical history can play a role. New and existing PILC and XLPE cable types have to be connected. Diffused demand for connection with straight plugs, cable-shoes and elbow and T-connectors has to be met. Dependent on the panel type, one or two cables per phase can be connected in large space accessible from the front on a height of 80cm.
The existing 10kV grid is rather old, and much safety rules and experiences are based on open stations. That's why features like a cable access-port often is required for testing and earthing cables without uncoupling the cable.

Operation and automation. Much attention has been given to design for simple and ergonomically operation. Good access to the improved instrument-box is provided as well. The option of control from distance is foreseen, which however so far in The Netherlands is not demanded regularly. A metal enclosed wiring channel is applied because of higher e.m.c.- requirements and possible automation in future.

CONCLUSIONS

Application of wind energy is increasing enormously, wind-turbines advance to units of more then 1MW and they are clustered into windfarms. These windfarms supply to HV stations, which puts new requirements to MV switchgear.
Completely insulated switchgear with integrated vacuum interrupters is environmental friendly and offers options for the higher ratings demanded. Fixed switchgear offers higher reliability and being free of maintenance. In the design features are offered for kWh-metering, advanced protection or larger feeders. Modularity adapts to future changing commercial applications of windfarms. The system can match many different existing cable and network situations.

ACKNOWLEDGMENT

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