Powerformer™ chosen for Swedish combined heat and power plant

Powerformer™, a radically new type of generator developed by ABB, has been chosen for a combined heat and power plant in Eskilstuna, Sweden. This first commercial order for Powerformer from the thermal power sector is for a generator rated at 42 MVA, 136 kV and 3000 rev/min. It will be connected directly to existing 136-kV switchgear, ie no step-up transformer will be used. The life-cycle cost of Powerformer is expected to be 15 percent lower than for a conventional generator.

After evaluating a life-cycle cost analysis which compared the overall economy of a conventional plant with that of a plant based on Powerformer generator technology, Swedish municipal utility *Eskilstuna Energi & Miljö AB* chose Powerformer for its new combined heat and power (CHP) station. The plant is being built next to an existing district heating power station in the city of Eskilstuna, some 100 km west of Stockholm. It is due to enter service in the year 2000 and is expected to operate for approximately 5,000 hours a year **1**.

The Eskilstuna CHP project

The new CHP plant at Eskilstuna will have an electrical rating of 38 MW and produce 71 MW of heat, plus another 15 MW of heat that will be recovered from the flue gases. Biomass, mainly forest and sawmill waste, will be used as fuel. Steam from the boiler, which is rated at 110 MW, will be fed to a steam turbine supplied by ABB Stal AB, Sweden. The turbine is a two-casing type, with a high-pressure and a low-pressure module. Powerformer, which is built by ABB Generation AB of Sweden, will be driven from both ends by the two steam turbine modules **2**.

Among the reasons for the utility choosing Powerformer were the high overall efficiency and the simplicity of the power plant configuration that the innovative concept makes possible. Both of these factors will favourably influence the life-cycle costs of the Eskilstuna CHP plant.

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Powerformer – a radically new generator

Powerformer employs a completely new generator technology to produce electric power at the high-voltage level. With Powerformer, it is not necessary to transform to a higher voltage level as in the case of conventional generators. By eliminating the step-up transformer, the electrical efficiency of the power plant is 0.5 to 2.0 percentage points higher than with traditional plants. Powerformer revolutionizes the established, traditional generator technology and represents a genuine milestone in the history of electrical engineering [1].

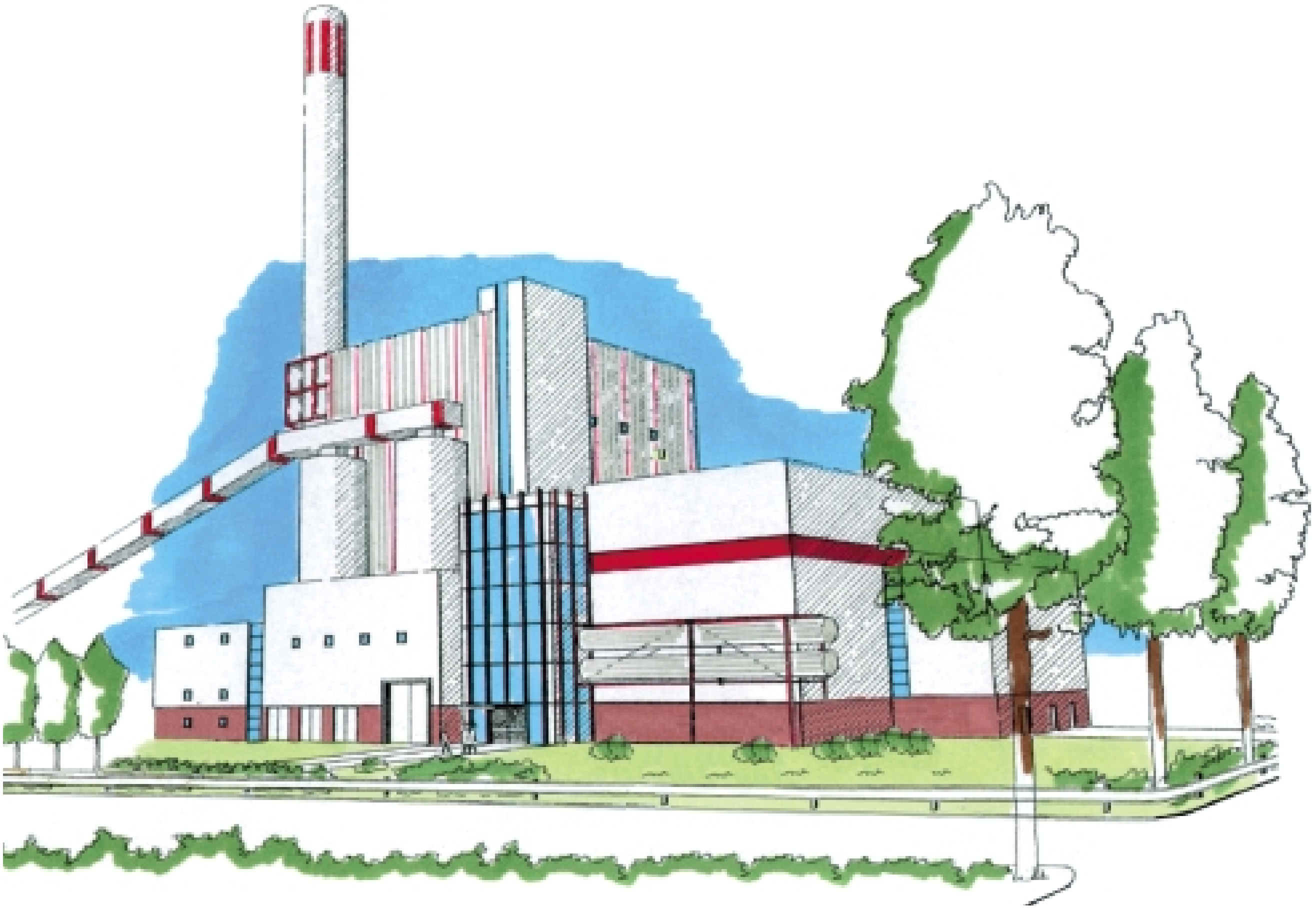
At first glance, Powerformer looks like a conventional air-cooled turbogenerator **3**. In fact, it essentially uses proven technology, with features that include:

- Air-cooled cylindrical 2-pole rotor
- Brushless exciter
- Pedestal bearings
- Laminated stator core
- Cylindrical stator frame

HV cables act as stator winding

In Powerformer, high-voltage cables with XLPE insulation replace the complex structure of square, insulated copper conductors that form the stator winding of a conventional generator.

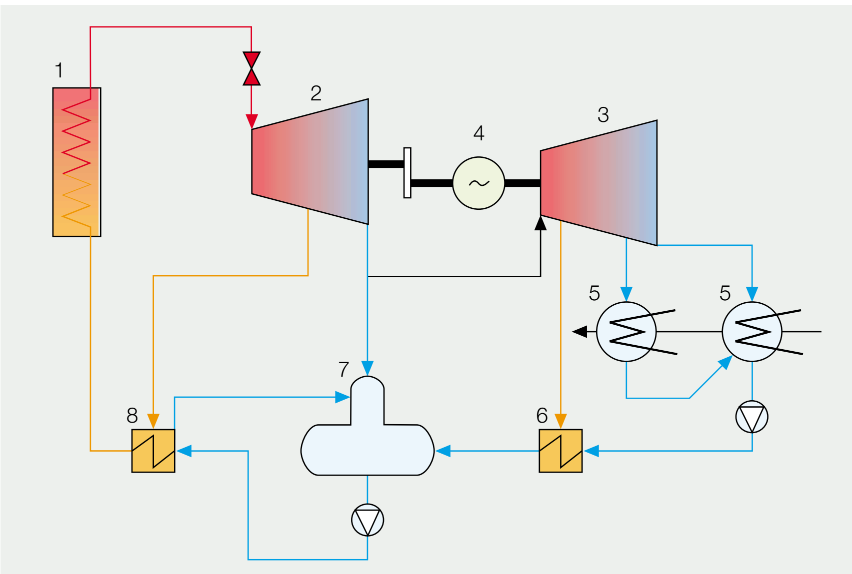
High-voltage cables with XLPE insulation are available today for voltages of up to 400 kV. When XLPE-insulated cables were introduced in the 1960s there were some initial problems with their reliability, caused by poor control of the manufacturing processes. These problems have since been overcome, and today's high-voltage XLPE-insulated cables have an impressive track record. A comparison of the number of faults in conventional generator windings with the number in high-voltage XLPE-insulated cables shows that the cables have fewer faults.



Artist's impression of the Eskilstuna combined heat and power plant **1**

Process diagram of the Eskilstuna CHP plant **2**

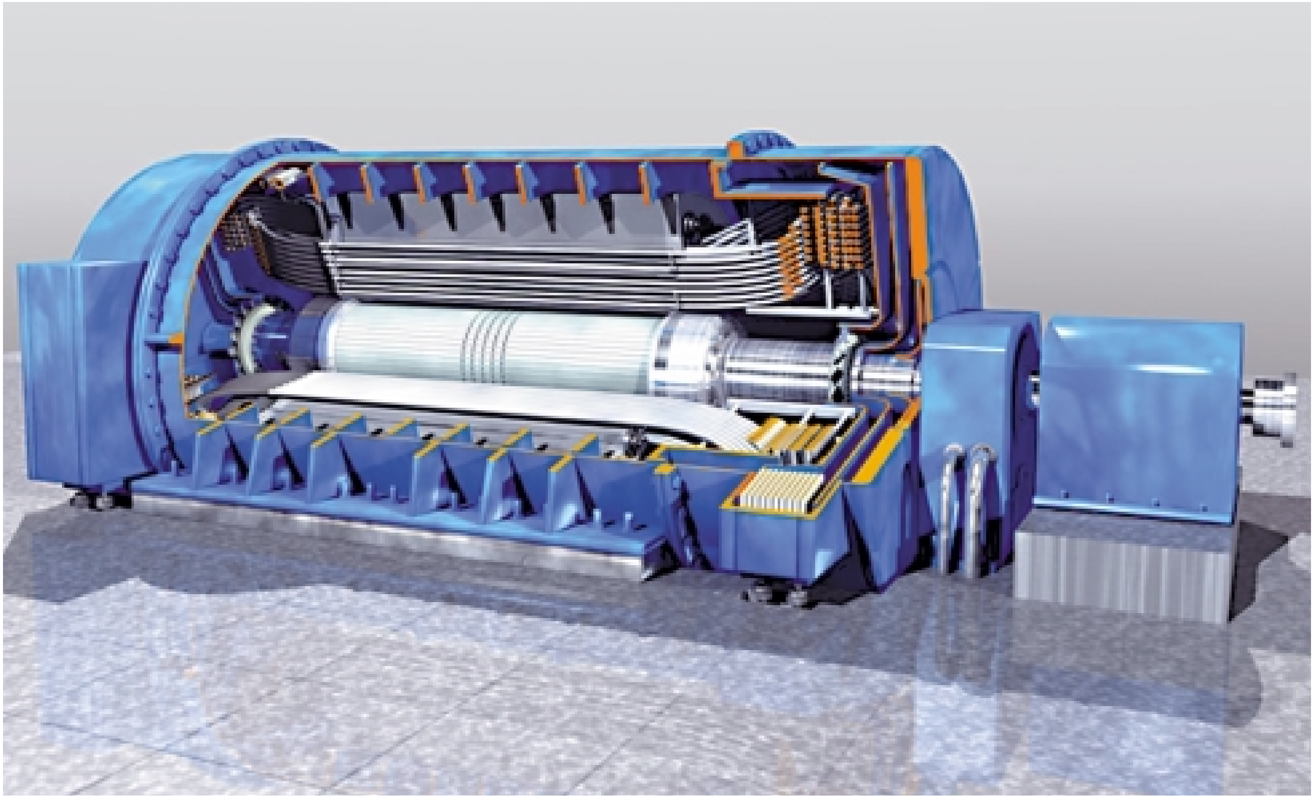
1 *Boiler*
2 *High-pressure steam turbine*
3 *Low-pressure steam turbine*
4 *Powerformer (high-voltage generator)*
5 *District heating condensers*
6 *Low-pressure preheater*
7 *Deaerator*
8 *High-pressure preheater*



The use of HV cables offers some important advantages. Firstly, the circular conductor geometry allows an evenly distributed electric field. This means that the insulation material is stressed uniformly. Secondly, the cable is designed for an electrical field stress of 10 kV/mm, a much higher figure than the 3 kV/mm that modern-day generator windings can manage. The combination of these two factors allows a dramatic increase in the generated voltage.

The use of high-voltage cables also ensures full insulation of the generator winding. With this arrangement the risk of partial discharge as well as internal two- and three-phase faults is minimized.

The stator current is considerably lower than with conventional generators on account of the higher generated voltage. The



Powerformer generator rated 136 kV for the Eskilstuna combined heat and power plant **3**

low current means that the mechanical forces acting on the end winding will also be low. As a result, the bracing system for the end winding can be made simpler than in the case of a conventional generator.

Cooling system

Powerformer has two cooling systems, both of them conventional and of proven design. The rotor and coil-ends are air-cooled by a closed ventilation system which uses air/water coolers to re-cool the air. The stator core is water-cooled by cooling-water pipes running axially in the core. Normal-quality cooling water can be used as the water remains at zero potential.

Losses and reactances

The losses in Powerformer are of the same order of magnitude as those in a traditional generator. However, they are distributed differently. Copper losses, stray losses and ventilation losses are lower, whereas iron losses are higher. The efficiency of Powerformer normally lies in the range of 97.5 to 98.5 %; for the Eskilstuna combined CHP plant the figure is 98.2 % (*Table 1*).

Powerformer can be designed with reactances of the same order of magnitude as a traditional generator/step-up transformer configuration. The short-circuit currents in the high-voltage switchgear are therefore also of the same order of magnitude.

Reduced environmental impact

Another important benefit of Powerformer is that its high efficiency reduces the envi-

Table 1
Powerformer for Eskilstuna CHP plant: technical data

Output	MVA	42
Power factor		0.93
Voltage	kV	136
Speed	rev/min	3000
Frequency	Hz	50
Cooling		
rotor		IC8A1W7 (air)
end winding		IC8A1W7 (air)
stator core		IC9W7W7 (water)
Efficiency		98.2 %

Table 2
Life-cycle cost analysis for the Eskilstuna CHP plant

		Plant based on Powerformer (%)	Conventional plant (%)
Investments			
Powerformer, 136 kV		100	
Generator, 11 kV			44
Generator busbars and switchgear, 11 kV			7
Transformer, 11/136 kV			26
Transformer building			5
Operation and maintenance			
Efficiency, 400 kWe lower output			22
Availability, 50 hours lower pa			11
Maintenance		Not evaluated	
Reactive power		Not evaluated	
Environmental impact		Not evaluated	
Total		100	115
Conditions:	interest rate	6%	
	operating hours	5000 pa	
	life-cycle	20 years	
	loss evaluation	USD 25/MWh	

ronmental impact of the power plant. Also, Powerformer contains fewer environmentally hazardous substances. For instance, no epoxy resin is used; this is in stark contrast to conventional generators, in which it is used to impregnate the stator coils.

As no step-up transformer is needed with Powerformer, the problems previously posed by the several tonnes of oil in the transformer tank are eliminated. The same applies to the oil-based insulation and cooling systems, which have been potential hazards in the past due to the risk of fire and oil leakage.

Other factors are the reduced electric and magnetic fields, which provide for a safer working environment in the plant.

Simplified and more efficient electrical package

Fewer components

The generator terminals are connected via high-voltage cables directly to the 136-kV switchgear situated some 1.3 km from the CHP plant. A 136-kV circuit-breaker takes over the function of the traditional generator breaker, with some very important advantages for the utility **4**:

- No 11-kV busbar is required.
- 11-kV generator switchgear is not required.
- No 11/136-kV step-up transformer is required.

A number of smaller components, eg current transformers, voltage transformers and surge arresters, are also eliminated. As a result, the Eskilstuna CHP plant will be considerably simpler than a conventional plant.

Powerformer has all the usual protection features, such as surge protection, generator protection and cable protection. For grounding, Powerformer utilizes the system grounding in the 136-kV switchgear. The generator neutral has a surge arrester for overvoltage protection.

Due to its fewer components, the Eskilstuna plant is also expected to require less maintenance.

Improved efficiency and reliability

By eliminating the generator busbars, generator switchgear and step-up transformer, losses are reduced by approximately 400 kW. Without these components, availability at the Eskilstuna plant is expected to be higher than in a conventional plant by about 50 hours per year.

Not only the active losses are reduced. A step-up transformer also consumes reactive power; since the step-up transformer, and therefore its reactive power losses, are eliminated, there is more reactive power available for the grid and to meet internal reactive power demand.

A higher efficiency has two other major benefits. More electric power can be pro-

Table 3
Powerformer for thermal power (output range 20–200 MW)

Output	MW	20–200
Voltage	kV	25–250
Speed	rev/min	3000/3600
Frequency	Hz	50/60
Drive	Steam turbine/gas turbine Single-end drive/double-end drive	

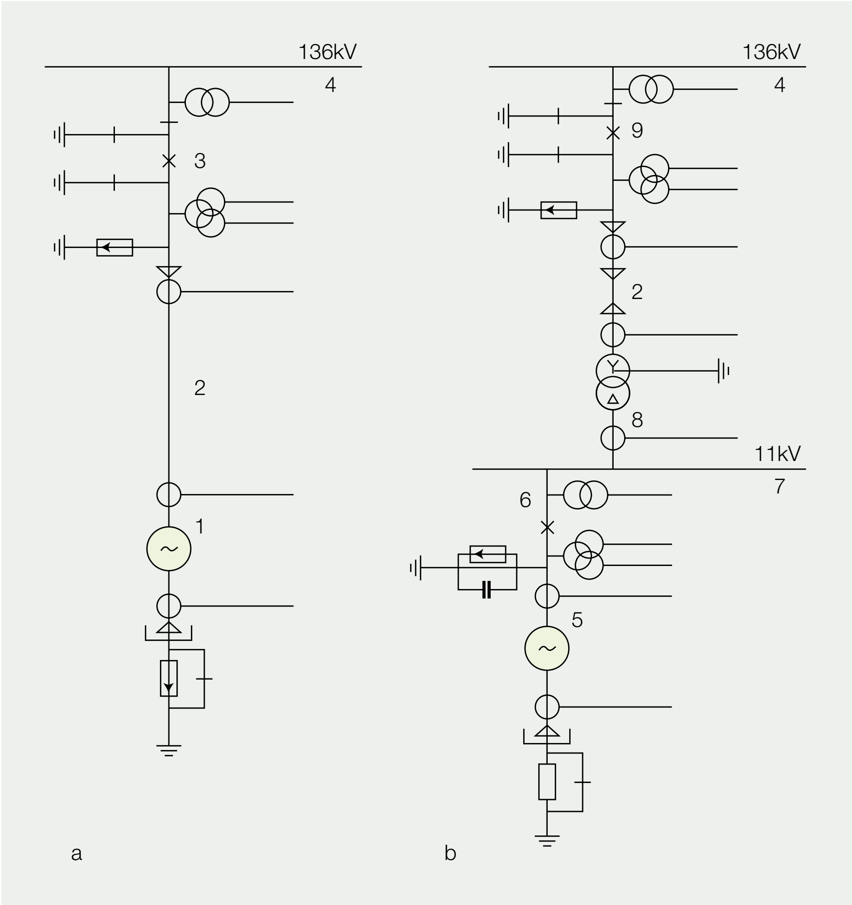
duced for the same fuel input or the same amount of electrical power can be produced using less fuel. Either way there are both commercial and environmental advantages.

15 percent lower life-cycle cost

Powerformer was developed in response to the power industry's drive to achieve more efficient operation and maintenance for generation plant. Powerformer offers advantages in technical performance that can be translated into economic benefits.

Eskilstuna Energi & Miljö selected Powerformer technology on account of its ability to generate cost-effective and environmentally friendly electric power. The utility estimates that its investment will be paid back within 7 to 10 years.

An analysis carried out by the utility, showed the life-cycle cost for a plant based on Powerformer technology to be 15 % lower than for a conventional plant (*Table 2*). This analysis took into account the investment cost, revenues and cost of operating the plant, interest rate, etc.



The electrical package – Powerformer (a) versus a conventional design (b) **4**

1 *Powerformer (high-voltage generator)*
2 *136-kV cable (1.3 km)*
3 *136-kV breaker (acting as generator breaker)*
4 *136-kV busbar*
5 *Conventional 11-kV generator*
6 *11-kV generator breaker*
7 *11-kV busbar*
8 *11/136-kV step-up transformer*
9 *136-kV breaker*

Powerformer now available for 20 to 200 MW

The key feature of Powerformer technology is the use of high-voltage cables instead of a conventional stator winding. This technology can be utilized basically in every kind of rotating electrical machine. ABB is developing the Powerformer concept for different applications, and at the present time it can be supplied for hydropower and thermal power generation plants. For thermal power applications, Powerformer is currently available in the output range of 20–200 MW and with voltages of 25–250 kV (*Table 3*). Development is continuing with the goal of increasing both the output and voltage.

Reference

[1] M. Leijon: Powerformer™ – a radically new rotating machine. ABB Review 2/98, 21–26.

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