POWERFORMER

Organisation of seminar

- Introduction
- Powerformer Concept
- Design
- Cooling system
- Advantages of Powerformer
- Comparison
- Conclusion
- Reference

Introduction

- For over 50 years, electricity has been produced by generators that conventionally operate at medium voltages, typically up to 25,000 volts (25kV).

- However, modern long-distance transmission systems use much higher voltages, so generators must be connected to the transmission networks by step-up transformers.

Introduction contd...

- The step-up transformer inflict great drawbacks on the power plant
- Starting from reduction in efficiency, high maintenance prices, and additional space, less availability and increased environmental impact of the plant.
- During the last century, a variety of attempts were made at developing a high-voltage generator that could be connected directly to the power grid, i.e. without going via the step-up transformer.

Introduction contd...

- Although grid voltages can reach 800 kV or more generators are presently constructed for voltages up to 30 kV , as stated above.

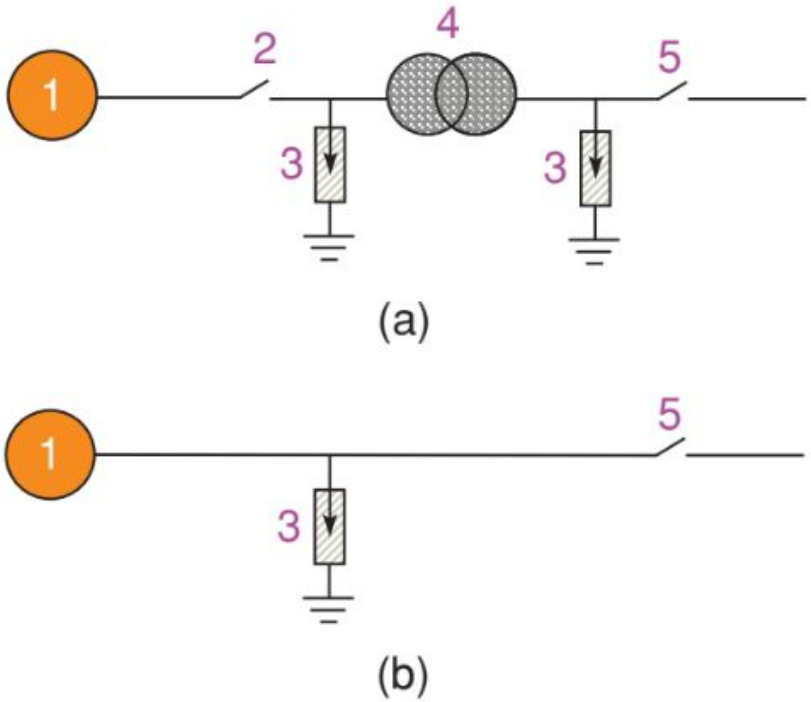
- ABB has created in close co-operation with Vattenfall (the Swedish state-owned power utility) a new high-voltage generator which can be connected directly to the transmission grid

Introduction contd...

- The output voltage will reach levels up to 400 kV. With the new technology, future transformer-less power plants can be constructed resulting to a new idea of energy systems.
- The new machine has been named Powerformer
- Its advantages such as higher efficiency, better availability, lower maintenance prices and reduced environmental impact

Powerformer Concept

- Powerformer is 3-phase AC generator with a rotor of conventional design that can be directly connected to power grid without the need of step-up transformer, its terminal voltage are 2~15 times higher than conventional generator.
- The difference compared with typical generator lies in the stator windings.
- In Powerformer stator winding consists of high-voltage cables rather than today's windings with a square cross-section



1. Generator
2. Generator circuit-breaker
3. Surge arrester
4. Step up transformer
5. Line circuit-breaker

Figure 1: Schematic diagram of a conventional plant with step-up transformer (a), and the same plant when the new technology is used (b).

- By using high-voltage cables as generator stator winding, it is possible to highly increase the generated voltage

- This design implies the omission of the generator circuit-breaker, the high current bus-bar and the step-up power transformer from the power plant, because Powerformer includes the functions of both generator and step-up transformer as realized from Figure (1).

- There is an increase up to 1.5% in total electric power efficiency compared with today's best designs

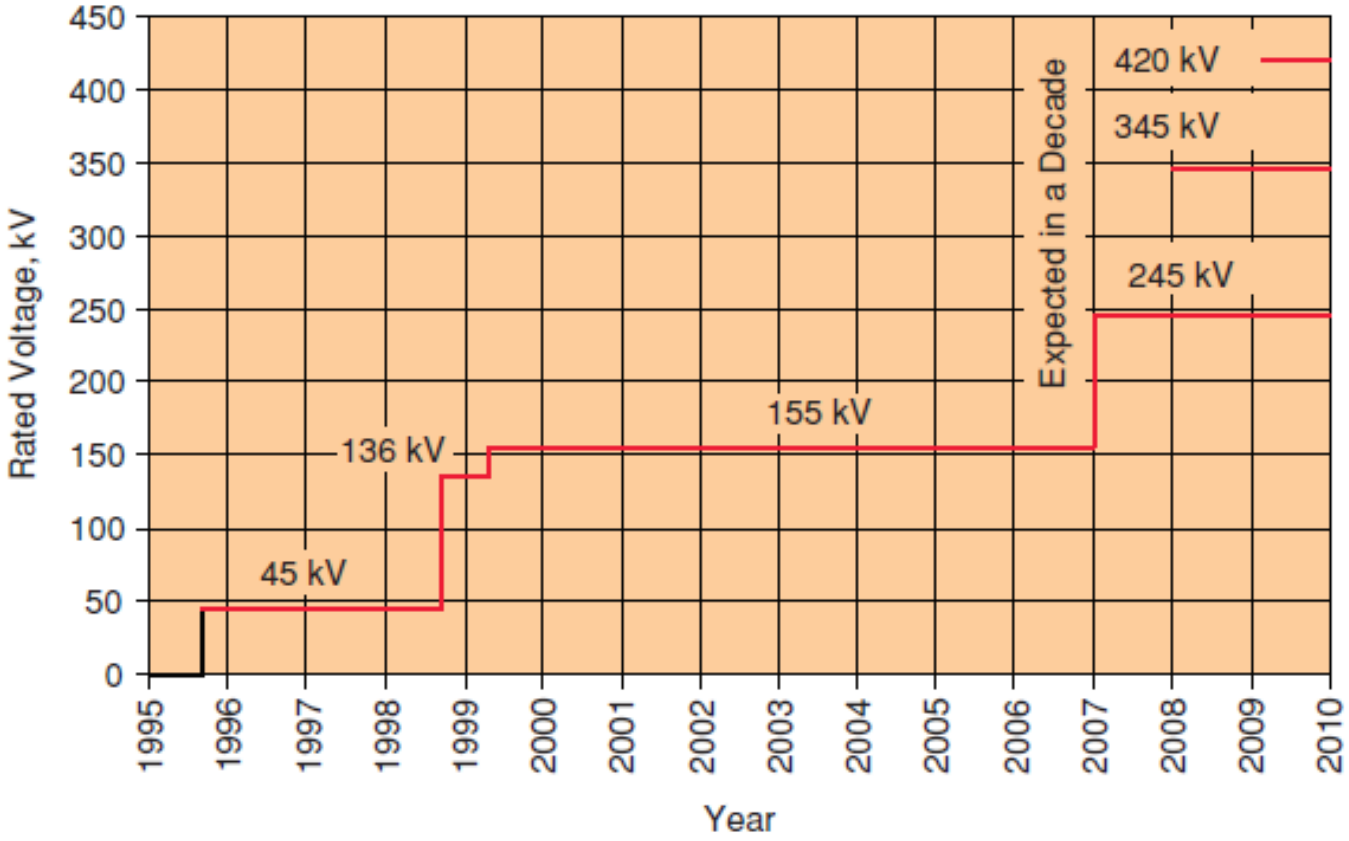


Figure 2: Development of Powerformer rated voltage.

Design

- **POWERFORMER WINDINGS**

- The winding consists of a power cable with solid insulation and two semiconducting layers
- one surrounds the conductor and the other outside the insulation
- The semiconducting layers serves as an equipotential surface that forces the electric field to be uniform around the circumference

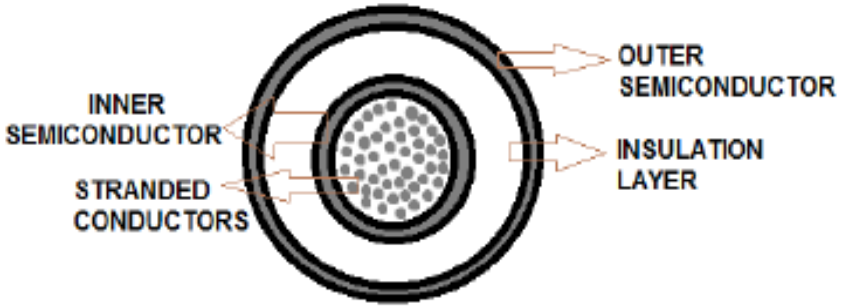


Figure 3: A cross section of stator winding of Powerformer.

- The insulation material is cross-linked polyethylene (XLPE), a material successfully used in high-voltage power cables since the 1960s.
- The cables are threaded through the stator slots to form a winding that produces the desired high-voltage

- The use of high-voltage cables in Powerformer windings offers major advantages over conventional designs

- In conventional generators maximizing the current loading in the machine favor the use of rectangular conductors in order to obtain maximum copper packing density for the stator windings

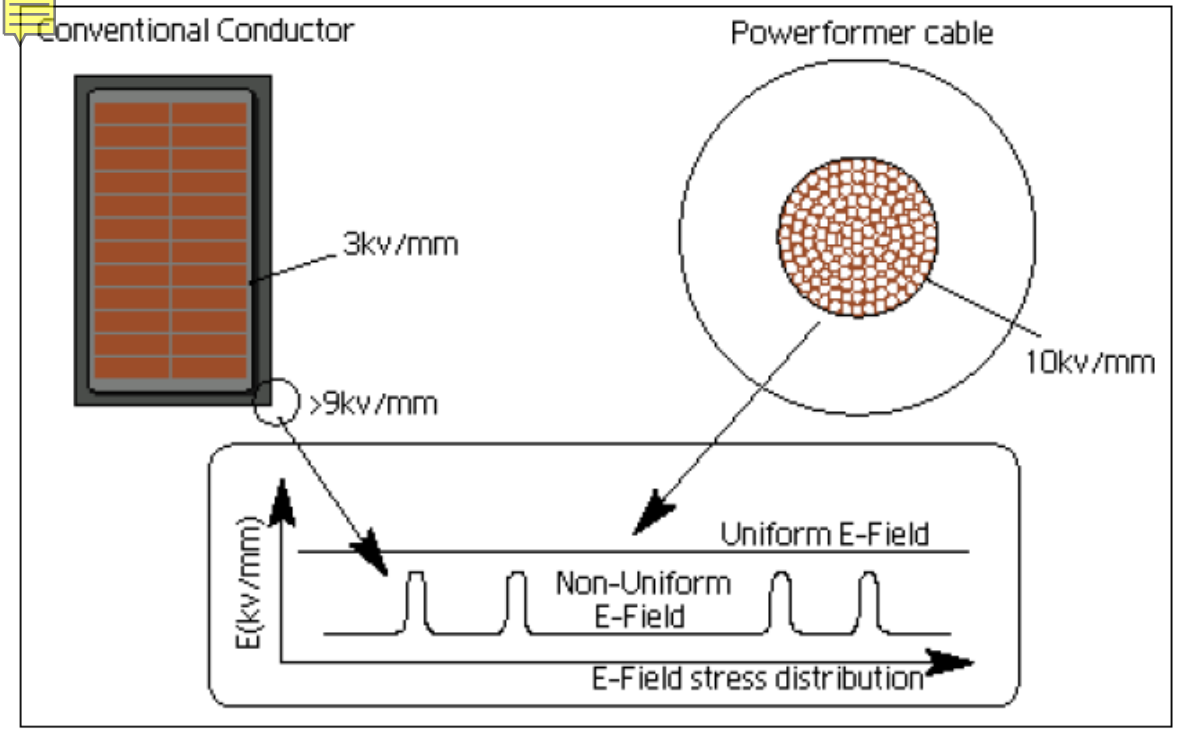


Figure 4:Comparison of conventional conductor and Powerformer cable

- Conventional conductor shapes are characterized by an uneven field distribution having high field concentrations in the corners of the conductors

- The cable circular cross section solves the basic problems arising from the use of conventional rectangular stator windings

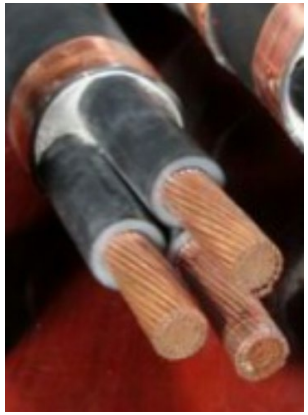
  - The circular geometry of Powerformer windings provides an evenly distributed electric field.
  - This means that the insulation material will be uniformly stressed and utilized in an optimum way
  - Bending a cable of circular cross section does not result in the sharp edges that arise with a rectangular cable

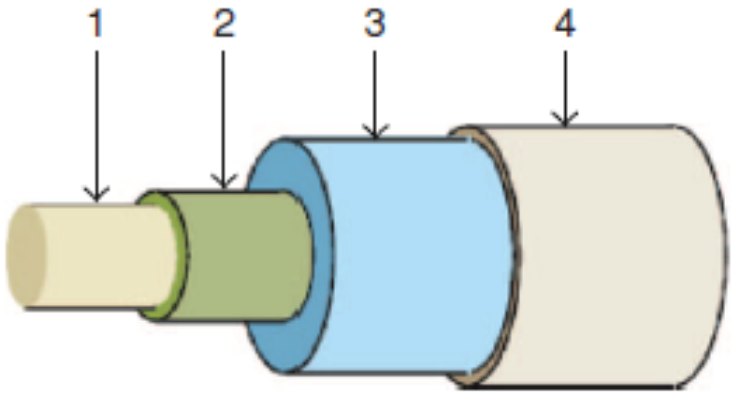
- In the end regions where the cable is bent to make the transition from one slot to the next, the electric field within the insulator remains free of singularities
- At the end regions of the Powerformer, the electric field remains confined within the cable.
- The need to control an external electric field, as in a conventional machine, is eliminated

❖ CABLE DESIGN

- Powerformer cable is designed for an electric field stress of 10 kV/mm and conventional generator cable is designed for 3 kV/mm
- The cables in the Powerformer have neither a metallic screen nor a sheath

- It consists of a stranded conductor, an inner semi conductive layer, a solid dielectric (normally an XLPE), and finally, an outer semi conductive layer.





1. Conductor,
2. Inner semiconducting layer
3. XLPE insulation
4. Outer semiconducting layer

Figure 5: Powerformer winding-cable

- The purpose of the inner semi conductive layer is to create a uniform electric field at the inner surface of the insulation layer
- The outer semi conductive layer acts to confine the electric field within the insulator

- The entire cable sheath (outer semiconducting layer) is connected to earth potential hence, the electric field outside the cable (in the coil-end region) is close to zero

- Since the outer sheath is at earth potential, there is no need for further control of the electric field.

- The conductor cross section will be dimensioned with respect to the prevailing system voltage and the maximum power of the generating unit

- A conductor used in an electrical machine is exposed for a higher magnetic leakage flux than a conductor used in transmission or distribution systems.

- In order to minimize the additional losses due to the magnetic leakage flux in the Powerformer conductors, it is necessary to subdivide the conductor into mutually insulated strands

- To ensure an equal electrical potential of the strands and the inner semiconducting layer, one or more of the strands in the outermost layer may be non-insulated.

- The induced voltage in a Powerformer stator winding will gradually increase from the neutral point to the line terminal.

- Therefore, the cable used for the stator winding is accordingly exposed for different electrical stresses along the length of the winding.

- It is therefore feasible, in a Powerformer, to use a thinner insulation for the first turns of the winding and thereafter increase the insulation thickness; it is called “stepped insulation”.

- To optimize the cost of cable and to have ability of several output level in terminals, three types of standard XLPE cable used 11, 33 and 63 kV in the stator slots Powerformer

- In each slot, there are 12 XLPE cables in such a way that two of the first cables near rotor surface 11 kV cable and the next four 33kV cables are behind them and the last six cables are 63 kV.

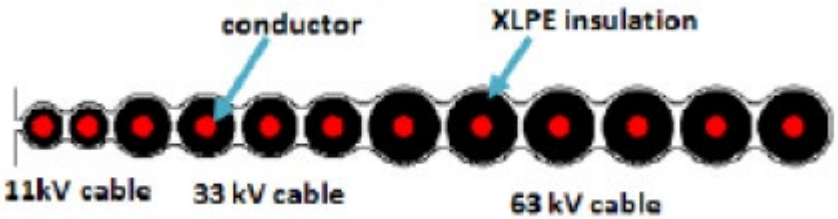


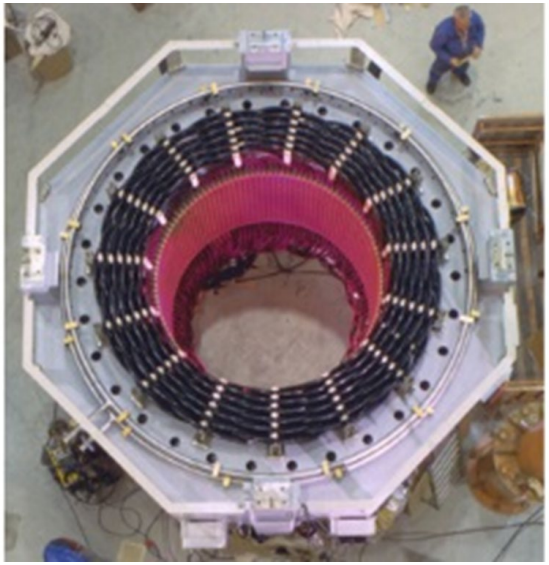
Figure 6:The proposed slot of Powerformer and the cables inside

- These features in combination highly increase the generated voltage. With high-voltage cables the generator windings will be fully insolated
- **Features of XLPE cables**

  - Higher conductor rating of 90 degree C
  - Have greater continues and short circuit current capacity
  - Super Clean Material Supplying System
  - Used in Thermal power station

❖ STATOR DESIGN

- The Powerformer stator consists of a laminated core, built up from electrical sheets. Teeth in the outer section point inward toward the rotor (at the center).
- The winding is located in the slots formed by the teeth. The cross-section of the slots decreases toward the rotor because each winding turn requires less cable insulation closer to the rotor
- Each slot has circular bores at intervals, forming narrow waists between the winding layers



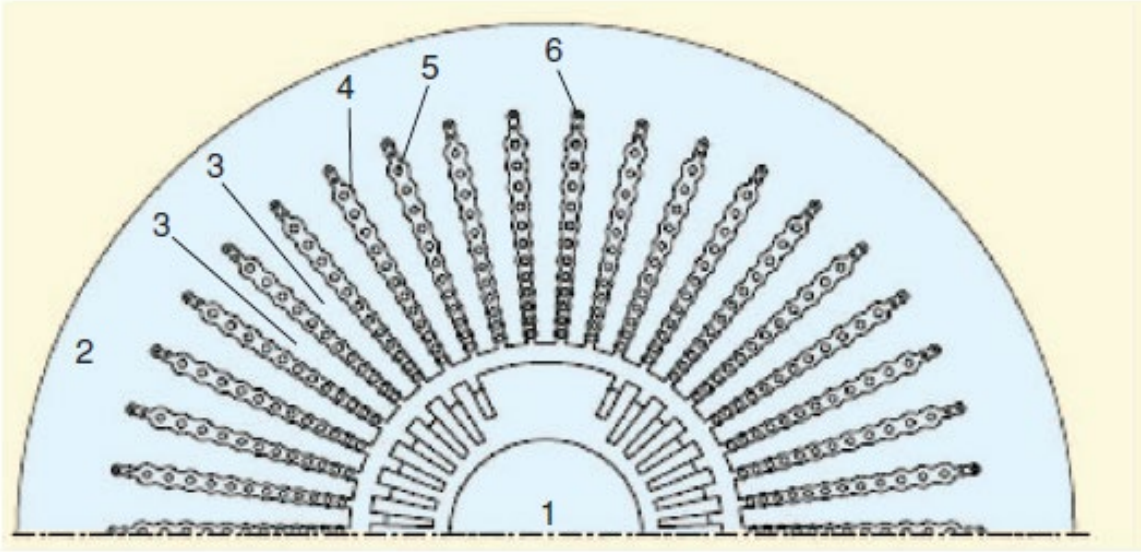


Figure 7: Stator view and Sectional view of the Powerformer stator

1. Rotor
2. Section of stator
3. Teeth
4. Slots
5. Main winding cable
6. Auxiliary winding

- As a result of using a high-voltage cable in the stator winding, an increase in the output voltage corresponds to a decrease in the loading current in the machine for a given power rating. Therefore, a lower current density results in lower resistive losses in the machine

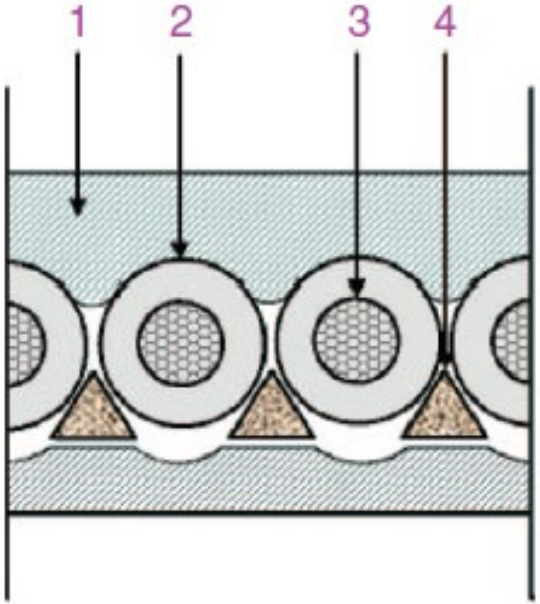
- The outer semiconducting layer cable is connected to earth potential. Hence, the electric field outside the outer semiconducting layer is close to zero in the coil-end region.

- Hence, there is no need to control the electric field in the coil-end region as in the conventional generator

- Another important aspect when designing a Powerformer is the minimization of the cable vibration

- To achieve this goal and to ensure good electrical contact between the cable and the laminated core, the cable is fixed in the slot. It is based on a triangular silicon rubber hose that is inserted between cables and slot wall

- The shape of the cross section of the rubber hose is designed to allow for elastic deformation necessary to keep the fixation forces within certain limits.
- The maximum force must be limited to reduce the elastic deformation of the cable cross section. A minimum force has to be maintained at low temperatures to avoid loss of contact between the cable and slot wall
- To avoid local deformation on the cable at the end-winding region due to vibration and bracing forces, the cables are separated from each other by a rubber distance element



1. Laminated stator core
2. XLPE insulation
3. Conductor
4. Fixation hose

Figure 8:Fixation of the winding cables in the Powerformer slots

Cooling System

- Most of the heat is generated in the stator core, which is grounded. This fact greatly simplifies the cooling system.

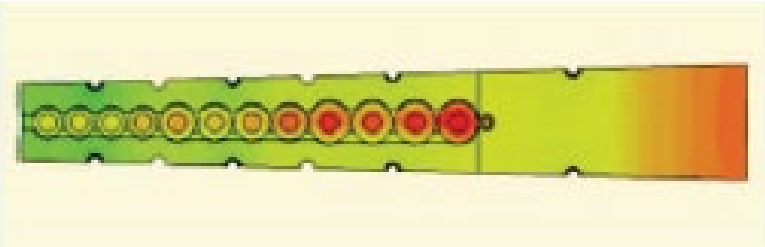


Figure 9:temperature distribution around a stator slot.

- The cooling system is an indirect system that cools the stator core by axially inserted water pipes made of high density XLPE.

- The stator has no radial air cooling ducts, and this leads to a homogeneous stator core. This makes the gross length of the stator shorter, the efficiency improves, and the stator assembly is more convenient, especially with respect to the cable installation through the slots.

- Tap water can be used and the use of plastic tubing also eliminates the risk of a short circuit

Advantages of Powerformer

- Powerformer concept results in major changes in the design, manufacturing and construction of a complete power plant along with its operation, these changes can a improve the economy of the whole power plant.

- The ability of Powerformer to replace the generator and step-up power transformer used in today's power plants, and produce a generated high voltage levels that enables the direct connection to the transmission power grid

- High energy efficiency (97.5% to 98.5%).
- Comparingly Much reliable.
- Robust in construction.
- Continuous operation.
- Low operating temperatures.
- Lower environmental impact
- Reactive power capability.
- Low maintenance cost

Comparison

Table 1. Conventional generator versus Powerformer

Conventional	Powerformer
Low Voltage (<30kV)	High voltage (>>30kV)
High current	Low current
High temperature	Low temperature
Short teeth	Long teeth
Impregnating windings	Extrusion
Mount winding	Thread cable
Overload capability = 1	Overload capability > 1
Reactive power cap. = 1	Reactive power cap. > 1

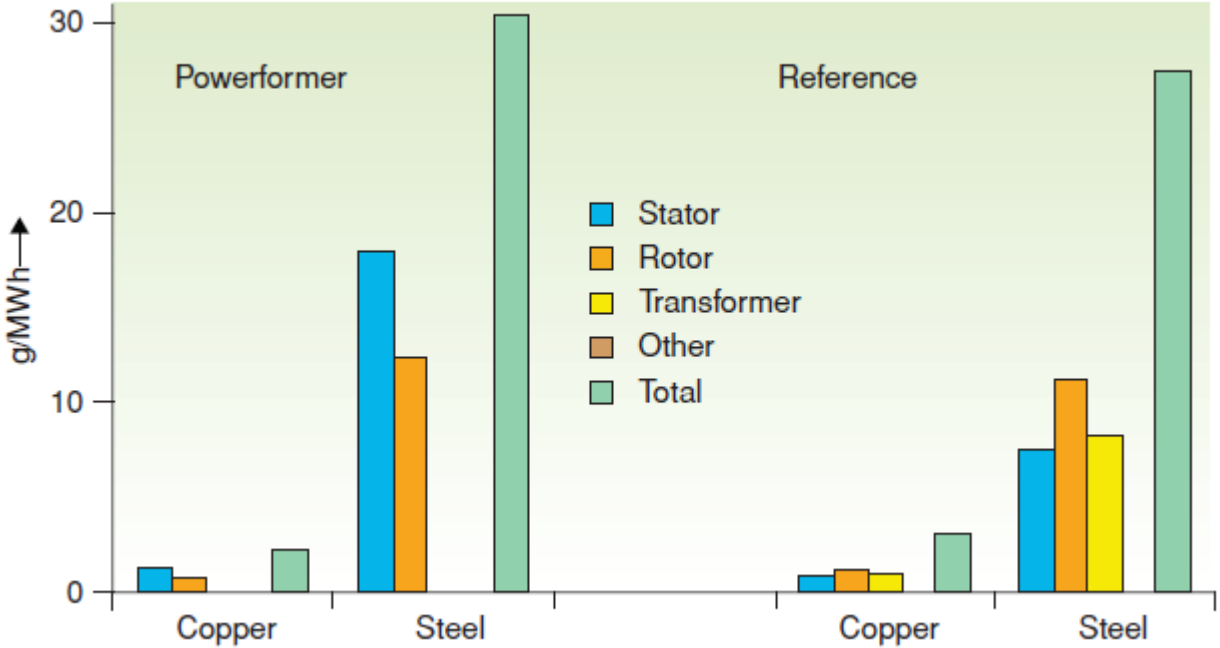


Figure 10 Net weight consumption of copper and steel in Powerformer and the reference system.

Conclusion

- The new high-voltage generator (Powerformer) and its design aspects has been studied through out this seminar; the concept provides the possibility to directly connect a rotating machine to the high-voltage power grid without going via a step-up transformer.
- The study illustrated that Powerformer offers great advantage to the plant economically, as it improves the system reliability and has an excellent overload handling capacity without any damage

Reference

- The story behind the high-voltage generator from ABB. HIGH VOLTAGE Magazine, ABB spring 1998
- M. Leijon, “Powerformer—A radically new rotating machine,” ABB Review 21–26, 1998.
- IEEE Trial-Use Guide to the Measurement of Partial Discharges in Rotating Machinery, IEEE Standard 1434–2000, 2000.
- M.Leijon,L.Gertmar, “breaking conventions in electrical power plant”.

- Ibrahim A. Metwally, R.M.Radwan, A.M. Abou-Elyazzied, “Powerformers: A breakthrough of high-voltage power generators” IEEE potentials, pp. 37-44, May 2008.

- F.Owman and T.Karlsson “ Power former:A Giant step in power plant engineering”