Transformer Handbook

ABB

0. FOREWORD

The objective of this Transformer Handbook is to facilitate the physical understanding, selection, ordering, operation and maintenance of the whole range of power and distribution transformers.

The target readers are personnel involved in the various stages of a transformer's service life, from planning the investment to the disposal of the transformer after use.

The handbook is arranged with the sections following the transformer's life from initial considerations and planning through ordering, installation, operation, maintenance and scrapping.

Other useful information, including more theoretical topics, is included.

Navigation through the handbook is facilitated through a three level contents list following this foreword, and the Index Section 19 page 210 at the end. Each section may be read independently of the other sections.

Some topics or phenomena are deliberately mentioned several places in the text for the purpose that readers might not read the whole content of this book from the beginning to the end, but only chapters of particular individual interest.

The first edition, Rev. 01, of this handbook issued at the end of 2003 was limited to distribution transformers and the "IEC-world".

Based on feedback from the readers and the fact that ABB has merged all transformer activities into one Business Unit, Transformers, this second edition of the handbook now covers all transformer types fulfilling the requirements of IEC and relevant ANSI/IEEE standards.

This handbook is based on ABB's knowledge and experience, and is meant to be a guide to assist the readers in handling transformer matters. ABB and the authors of the handbook cannot however be held responsible for any legal, technical or commercial use of the information herein.. No advice or information contained in this handbook shall create any warranty or binding obligation not expressly stated in an applicable written contract. Although data, technical drawings, configurations and catalogue listings are believed to be accurate at the date of publication, the readers should independently evaluate the accuracy of the information and the usefulness to their particular needs of any product or service. However, technical data are only approximate figures. Specifications for products and services are subject to change without notice.

ABB shall in no case be liable under, or in connection with, the handbook towards any person or entity in view of any damages or losses - irrespective of the legal grounds. In particular ABB shall in no event be liable for any indirect, consequential or special damages, such as – but not limited to – loss of profit, loss of revenue, loss of earnings, Cost of capital or cost connected with an interruption of business.

The standards, IEC, CENELEC and ANSI/IEEE, mentioned in the text refer to the edition given in the list of standards. For practical use only latest editions of the standards should be used.

UK English has been selected for this document to comply with the language in IEC standards. Also the use of "." and "," in numbers follows the practice used in IEC standards. There are no real differences between the vocabulary applied in IEC and IEEE/(ANSI) standards. The only exception is the use of the words "earth"/"earthed" (according to IEC) and "ground"/"grounded" (according to IEEE).

Please also observe the Note at the end of the handbook.

CONTENTS

1. INTRODUCTION

In almost every place where people live and work you will find at least one transformer. But as long as it keeps working and supplying power to the escalator in the department store, the hotel lift, the office computer, the oven in the local bakery, the farm machinery or the petrochemical plant nobody gives it a second thought.

However, transformers are one of the most important units in every production process. Without them the core activities of nearly every business and factory would come to a standstill – with serious financial consequences.

After more than 100 years in the development and manufacture of transformers, ABB Transformers are well aware of this dependence. This is why we never compromise on the performance, security, quality or reliability of our products, nor on design, materials, manufacturing methods, environmental protection or recycling.

All over the world, in underground railways, in amusement parks and in every kind of factory you will find ABB transformers at work.

1.1. ABB-GROUP

ABB is a leader in power and automation technologies that enable utility and industry customers to improve performance while lowering environmental impact. The ABB Group of companies operates in around 100 countries and employs around 115,000 people (2004).

ABB Power Technologies serves electric, gas and water utilities as well as industrial and commercial customers, with a broad range of products, systems and services for power transmission, distribution and automation.

ABB Automation Technologies blends a robust product and service portfolio with end-user expertise and global presence to deliver solutions for control, motion, protection, and plant integration across the full range of process and utility industries.

As a business-to-business supplier ABB knows that value creation grows out of close relationships with customers. That means the better we know our customers' business challenges, the better we can serve them. We strengthen our relationships by building trust as a socially responsible supplier of environmentally sound products and services.

1.2. ABB Power Technologies Business Unit Transformers

ABB is among the worlds leading suppliers of transformers offering a full range of products (liquid/dry), tested according to and fulfilling specified requirements in all widely applied standards, such as IEC, CENELEC, ANSI/IEEE as well as local standards.

ABB Transformers has almost 60 production facilities around the world with 13 000 employees (2004).

All of this means that with ABB Transformers you have access to a world-wide network of factories and facilities serving you locally with the most up to date technologies, providing the highest quality for standard and speciality products as well as solutions. Our warranty provides ABB quality, service and support. Our production facilities are ISO 9001/14001 certified.

ABB Transformers objective is to support you and to add value to your activities with a low total cost of ownership.

highest quality for standard and speciality products as well as solutions. Our warranty provides unified ABB quality, service and support. Our production facilities are ISO 9001/14001certified.

ABB Distribution Transformers objective is to support you and to add value to your activities with a low total cost of ownership.

2. TRANSFORMER TYPES AND THEIR APPLICATION

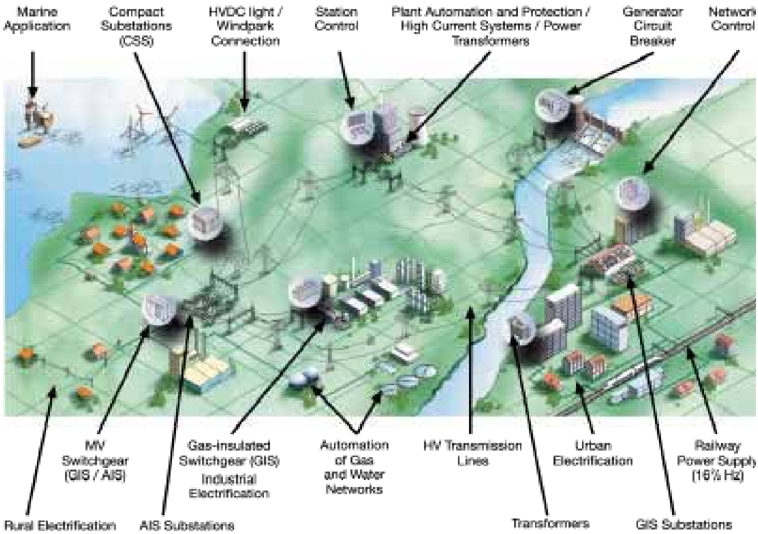
2.1. POWER GENERATION, TRANSMISSION AND DISTRIBUTION

Transmission of energy is generally divided in two parts; first is transmission over long distances at high voltages, which is supported by Power Transformers. The second part is distribution of the energy from substations to the various users; this is supported by Distribution Transformers in various hierarchies.

Power and Distribution Transformers

ABB offers a full range of transformers fulfilling the requirements in IEC, CENELEC, ANSI/IEEE, other standards and customer-specific requirements.

Power transformers have primary voltages up to 800 kV. Liquid filled distribution transformers have primary voltages up to 72,5 kV and dry-type transformers with open or encapsulated windings have primary voltages up to 52 kV.



2.2. COMMON TRANSFORMER CHARACTERISTICS

In IEC Standard 60076-1 Power transformers Part 1: General, a power transformer is defined as a static piece of apparatus with two or more windings which, by electromagnetic induction, transforms a system of alternating voltage and current into another system of voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power.

The same definition is found in the International Electrotechnical Vocabulary [IEV 421-01-01].

The scope of this standard includes single-phase transformers with rated power down to 1 kVA and three-phase transformers down to 5 kVA.

IEC standards do not distinguish between distribution transformers and power transformers. They are all power transformers in the sense that their purpose is to transmit power from one voltage level to another.

Traditionally, transformers that transform the voltage down to the domestic consumer voltage (usually 400 V or less) are called distribution transformers. ABB includes transformers with the highest voltage up to 72,5 kV and power rating up to a few tens of MVA in the category distribution transformers. The term power transformer is in everyday language used for transformers with higher voltage and power rating.

Common for most power transformers regardless of size and application is the basic physics and the dominant materials, like:

- special types of thin magnetic steel plates in the core, which provides the necessary strong magnetic field because of the unique magnetic properties of iron. Without iron the widely spread application of electric energy would be impossible;
- copper or aluminium as conductor materials in the windings;
- cellulose products like high density paper and pressboard as solid insulation materials has been and with few exceptions still is dominant;
- mineral oil is the dominant insulating fluid, which also has a cooling function.

In practical transformer design the manufacturer has the choice between two different basic concepts:

- core-type, see Figure 2-1
- shell-type, see Figure 2-2

The one or the other of these concepts has no influence on operational characteristics or the service reliability of the transformer, but there are essentially differences in the manufacturing process. Each manufacturer chooses the concept that he finds most convenient from a manufacturing point of view and tends to use this concept for the whole production volume.

In a nutshell we can say that while the windings of a core-type enclose the core, the core of a shell-type encloses the windings. Looking at the active part (i.e. the core with the windings) of a core type, the windings are well visible, but they hide the core limbs. Only the upper and lower yoke of the core are visible. In shell-type the core hides the major part of the windings.

Another difference is that the axis of the core-type windings is normally vertical while it can be horizontal or vertical in a shell-type.

Today much more core-type transformers than shell-type power transformers are manufactured in the world. The common transformer concept in ABB is the core-type.

Core type

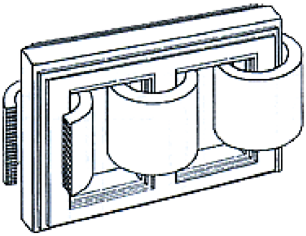


Figure 2-1

Shell type

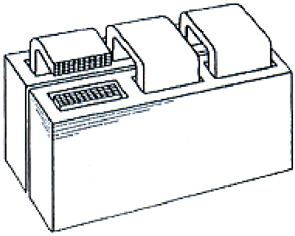


Figure 2-2

A wound type of core used in single-phase distribution transformers is shown in Figure 2-3.

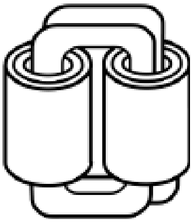


Figure 2-3

2.3. DISTRIBUTION TRANSFORMERS

2.3.1. Large distribution transformers, LDT

IEC Standard

Power range	5000 kVA and above
Primary voltage	Up to 72,5 kV
Available fluids	Mineral oil, dimethyl silicone, esters and synthetic hydrocarbons

Transformers of this type are used for receiving the energy from higher voltage levels and to transform and distribute the energy to lower voltage level substation or directly to large industrial consumers.

Transformers in this range are three phase and can be manufactured with off-circuit tap changer or on-load tap changer. Transformers provided with on-load tap changer usually have a separate tap winding.

The core is constructed of grain oriented steel laminations. The windings are made of paper insulated rectangular wire in the form of multi-layer disc or helical windings, and the conductor materials are either copper or aluminium. The tanks typically have radiators, however the smaller sizes might have corrugated tank walls.

ANSI / IEEE Standard

Substation and Unit Substation

Power range	112,5 kVA - 20 MVA
Primary voltage	Up to 69 kV
Secondary voltage	Up to 34,5 kV
Available fluids	Mineral oil, dimethyl silicone, esters and synthetic hydrocarbons

The Substation and Unit Substation Transformer are three phase and can be manufactured with off-circuit tap changer or on-load tap changer. The core is made of grain oriented silicone steel laminations. The coil is made of either aluminium or copper both in high and low voltage windings. The tank is equipped with radiators.

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Substation transformers are supplied with cover mounted bushings for connection to overhead utility lines and Unit Substation transformers with wall mounted bushings on either the primary, secondary or both sides of the transformer for close connection to associated switchgear.

Padmounted transformers

Power range	75 kVA - 20 MVA
Primary voltage	Up to 46 kV
Secondary voltage	Up to 25 kV
Available fluids	Mineral oil, dimethyl silicone, esters and synthetic hydrocarbons

This type of transformers is designed for shopping centres, apartment and office buildings, schools and industrial locations etc. They can be UL (Underwriters Laboratory) listed and are used where power is needed in close proximity to the general public by commercial, industrial and utility customers.

The design provide a resistant robust construction with no externally accessible bolts, hinges, screws or fasteners providing a safe, self-contained unit that prevents entry by un-authorized personnel. Unsightly fences or other personal safety protection are not necessary.

2.3.2. Medium distribution transformers, MDT

IEC Standard

Power range	400 – 5 000 kVA
Primary voltage	Up to 36kV
Available fluids	Mineral oil, dimethyl silicone, esters and synthetic hydrocarbons.

Transformers of this type are used to step down three-phase high voltage to low voltage for energy distribution, mainly in metropolitan areas and for industrial applications.

The transformers in standard versions are three phase hermetically sealed. Flexible corrugated tank walls enable sufficient cooling of the transformer and compensate for changes in the oil volume due to temperature variations during operation.

An advantage of hermetically sealed transformers is that the oil is not in contact with the atmosphere thus avoiding absorption of moisture from the environment.

On customer request, the transformer may be equipped with oil conservator.

ANSI / IEEE Standard

Network transformer

Power range	300 kVA - 2500 kVA
Primary voltage	Up to 34.5 kV
Secondary voltage	Up to 600 V
Available fluids	Mineral oil, dimethyl silicone, esters and synthetic hydrocarbons

Networks transformers are commonly used in a grid-type secondary system in areas of high load density required for large cities. Network Transformers are designed for either subway or vault applications. Network transformers are designed for frequent or continuous underground operation.

Padmounted transformer

Power range	Up to 5000 kVA
Primary voltage	Up to 34,5 kV
Secondary voltage	Up to 4,16 kV
Available fluids	Mineral oil, dimethyl silicone, esters and synthetic hydrocarbons

This type of transformer is designed for shopping centres, apartment and office buildings, schools and industrial locations etc. They can be UL (Underwriters Laboratory) listed and are used where safe reliable power is needed in close proximity to the general public by commercial, industrial and utility customers.

The design provide a resistant construction with no externally accessible bolts, hinges, screws or fasteners providing a safe, self-contained unit that prevents entry by un-authorized personnel. Unsightly fences or other personal safety protection are not necessary.

2.3.3. Small distribution transformers, SDT

IEC Standard

Power range	Up to 315 kVA
Primary voltage	Up to 36kV
Available fluids	Mineral oil, dimethyl silicone, esters and synthetic hydrocarbons.

Transformers of this type are used to step down three-phase high voltage to low voltage for energy distribution, mainly in the countryside or low-density populated areas.

The transformers are three phase oil immersed hermetically sealed, adaptable for pole mounting or assembly in substations.

On customer request, the transformer can be equipped with an oil conservator.

Hot dip zinc coating is often the preferred surface treatment for outdoor applications.

Single Phase Polemounted

Power range	5 - 100 kVA
Voltage	Up to 36 kV
Applicable fluid	Mineral oil

Transformers of this type are generally oil immersed and suitable for pole mounting. They represent an economical option for certain networks, particularly those with low population densities. Depending on customer requirements, transformers may be connected between two phases of a three phase system (two HV bushings) or from one phase to ground (single HV bushing). They are suitable for residential overhead distribution loads, as well as light commercial or industrial loads and diversified power applications.

ANSI / IEEE Standard

Padmounted transformers

Power range	45 kVA - 150 kVA
Primary voltage	Up to 25 kV
Secondary voltage	Up to 480 V
Available fluids	Mineral oil, dimethyl silicone, esters and synthetic hydrocarbons

The Mini-Three Phase Padmounted Transformer (MTP) is designed for the needs of utility customers to reduce costs and improve aesthetics. This type is easy to handle, install and maintain. The discreet profile of the MTP is ideal for commercial applications such as banks, stores and restaurants. The MTP features a hood and removable sill instead of doors. The design allows easy access for installation and maintenance of the transformer.
The connection cables are arranged underneath the transformer.

Polemounted transformers

Power range - 1 Phase	5 kVA – 1 000 kVA
Power range - 3 Phase	30 kVA - 500 kVA
Primary voltage	Up to 36 kV
Secondary voltage	Up to 480 V
Available fluids	Mineral oil, synthetic hydrocarbons

The Polemounted distribution transformers are specifically designed for servicing residential overhead distribution loads. They are also suitable for light commercial loads, industrial lighting and diversified power applications

The Polemounted transformers are available in both single and three phase designs. ABB also offers triplex designs for applications where large motors are the loads, e.g. for oil pumping and irrigation. "T-Connected" (Scott) three phase designs are available to serve most three-phase applications.

Single Phase Padmounted

Power range	10 kVA - 250 kVA
Primary voltage	Up to 25 kV
Secondary voltage	Up to 480 V
Available fluids	Mineral oil, dimethyl silicone, esters and synthetic hydrocarbons

The Mini-Pak is designed for cross feed (Type 2) loop feed or radial feed on a grounded wye connection, underground distribution system. It can be furnished in a complete line of ratings and in a wide range of configurations to meet the reliability, safety and operating requirements of any distribution system.

2.3.4. Dry-type distribution transformers

Dry-type transformers are used to minimize fire hazard and other environmental contamination on surroundings and people, like in large office buildings, hospitals, shopping centres and warehouses, sea going vessels, oil and gas production facilities and other sites where a fire has potential for catastrophic consequences.

ABB offers a full range of dry-type transformers with primary voltages up to 52 kV, fulfilling the requirements in IEC, CENELEC and ANSI/IEEE standards.

Application areas for both types are quite similar; however Resibloc® has an advantage in extreme climatic conditions.

2.3.4.1. Vacuum cast resin dry-type transformers

Power range	50 kVA up to 30 MVA
Primary voltage	Up to 52 kV
Climate class	C2 (IEC 60076-11)
Insulation class	220 °C (ANSI/IEEE)

Vacuum cast means that the high voltage windings are cast-in in epoxy and cured in vacuum. The high voltage windings are typically disc winding.

Typical IEC product

Typical ANSI product

2.3.4.2. Resibloc® dry-type transformers

Power range	30 kVA up to 40 MVA
Primary voltage	Up to 52 kV
Climate class	C2 (IEC 60076-11)
Insulation class	220 °C (ANSI/IEEE)

Resibloc® is an ABB patented process for the high voltage winding. The high voltage winding is multi layer type with a cross wound glass fibre insulation soaked in epoxy, cured in open atmosphere.

Typical IEC product

Typical ANSI product

ANSI / IEEE Standard

VPI (Vacuum pressure impregnated) and
VPE (Vacuum pressure encapsulated) dry type transformers

Power range	Up to 15 MVA
Primary voltage	Up to 35 kV
Insulation class	220 Degree C

VPI transformers feature a single coat of polyester varnish and VPE transformers feature a multiple coating of silicone resin for enhanced environmental protection. They always use UL (Underwriters Laboratory) listed materials for 220°C temperature class.

VPI (Vacuum pressure impregnated)

VPE (Vacuum pressure encapsulated)

2.3.5. Other transformer types

2.3.5.1. Drives transformers

Variable Speed Drive (VSD) transformers provide the voltage transformation as well as electric isolation that is necessary for motor drives applications. Converter drives are normally fed by medium voltage networks from 5 kV up to 36 kV and the converter supply voltage usually ranges from 400 V up to 4 kV. The VSD transformer transforms the medium network voltage to the converter supply voltage. A typical application is submersible oil pump drives and similar equipment where only HV motor applications are available. VSD transformers are produced in oil insulated and dry-type configurations up to 6 MVA ratings for various types of converters and output voltages. Transformers are individually designed and manufactured according to system requirements.

2.3.5.2. *Wind turbine applications*

Dry-type and liquid-immersed transformers for wind turbine application are special design with low losses and small outer dimension in the transversal direction, enabling the unit to be transported through narrow door openings.

<u>Dry-type</u>

Power range	1000 kVA up to 2100 kVA or higher on request
Primary voltage	Up to 36 kV
Climate class	C2 (IEC 60076-11)

Special features:

- LV terminals are located at the bottom.
- No bottom frame or wheels.
- Option for a tertiary winding for auxiliaries load.

<u>Liquid immersed</u>

Power range	up to 4000 kVA
Primary voltage	up to 36 kV
Available fluids	Dimethyl silicone or esters

Special features:

- Hermetically sealed
- Hot-dip zinc coated and painted
- Plug-in bushings on HV side
- Protected LV bushings
- Integrated protecting device; gas, oil level, temperature, pressure

2.3.5.3. *Sub sea transformers*

Power rating	On request
Primary voltage	Up to 72,5 kV
Secondary voltage	1 - 12 kV
Maximum depth	2000 m
Available fluids	Mineral oil

The challenge with off-shore free flow oil production is the decreasing pressure inside the oil well. The pressure drop decreases the production lifetime of the well and the production depth.

Sub sea booster pumps makes oil production at larger depth possible caused by an artificial lift to the oil. The pumps are driven by low voltage electrical motors. The power is supplied by long HV cables from the production vessels. The main reasons for using HV supply are to reduce the weight of the cables as well as the voltage drop in the cables. Step-down transformers are installed at the sea-bed near the booster pumps.

2.3.5.4. *Underground transformers*

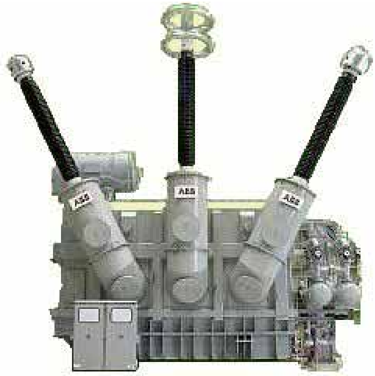
ANSI / IEEE Standard

Power range	75 - 1000 kVA
Voltage	Up to 30 kV
Applicable fluid	Mineral oil, esters and synthetic hydrocarbons

The Underground Commercial Transformer (UCT) is designed for loop feed, dead front application and is equipped with bayonet fusing or drywell current limiting fuse protection interlocked with an LBOR oil loadbreak rotary switch. There are six welded-in high voltage universal bushings wells for loop feed connection.

2.4. POWER TRANSFORMERS

Transformer manufacturers face several challenges in the design of large power transformers with extra high voltages (EHV) that is system voltages up to and including 800 kV.



3 phase power transformer 400 MVA

Transient overvoltages

One of the challenges is to enable the designer to predict the transient voltage distribution within windings when transient voltages of certain shapes are applied to the transformer terminals. The voltage distribution varies, depending on a number of winding parameters. Comprehensive measurements with modern measuring equipment on a large number of windings of various types have been made in order to develop mathematical models for calculation of the voltage distribution. This development has in ABB gone on for many years with gradually decreasing deviations between calculated and measured values.

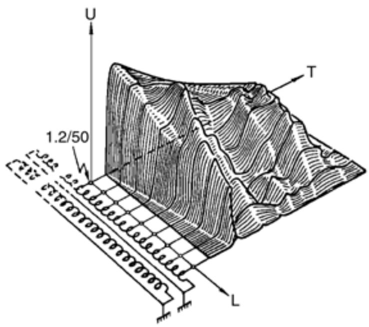


Figure 2-4

Figure 2-4 shows an example of the voltage distribution in a winding when a standard lightning impulse (with 1,2 microsecond front time and 50 microseconds time from start to the voltage has declined to half the peak value) is applied to the winding terminal. The length of the winding is indicated along the L axis, and the time along the T axis. The measured voltages to earth are indicated along the U axis.

The figure reminds one of a stony hill. Where the hill is very steep in the L direction, there are large voltage differences between points in the winding that are nearby each other.

The ability of the insulation to withstand the local dielectric stresses at numerous different spots in the winding is not only dependent on the peak value of the stress but on its duration as well. ABB has done in-depth research on basic dielectric phenomena in transformer insulation, and ABB's present competence on enabling transformers to withstand transient overvoltages is the result of several decades of work. However, the service reliability of the transformer is based on the condition that the transformer is adequately protected against transient overvoltages in compliance with good insulation co-ordination practice.

Unlike the smaller distribution transformers, which to a considerable degree are standardised, large power transformers are usually individually designed.

The magnetic leakage field

The magnetic leakage field increases with the power rating and the short circuit impedance of the transformer. For the largest transformers special precautions must be taken to ensure that the leakage field does not cause harmful heating in windings and structural parts like core clamps and tank.

Excessive heating causes gas bubbles, which represent weak points in the oil. If such bubbles rise through dielectric high-stress areas in the transformer, breakdown may occur. In addition, hot spots in contact with the oil will deteriorate the oil. For many years ABB has made comprehensive studies of the leakage field and the temperature distribution in transformers by means of thermocouples and fibre optics to obtain knowledge on how to avoid hot points that could jeopardise the service reliability of the transformers.

Mechanical forces

A third important topic is to make large power transformers able to withstand the large mechanical pulsating forces that arise during short circuit currents through the windings. Large power transformers are normally installed in systems with very high short circuit power. While thermal or economic loss considerations usually determine the current density in the winding conductors of smaller transformers, the mechanical stresses during short circuit currents often determine the winding conductor cross section in some windings of larger transformers.

The basis of ABB's design rules and manufacturing practice to achieve transformers with ability to withstand short circuit currents is theoretical considerations combined with experience from full short circuit current testing of complete transformers. More than one hundred power transformers of all sizes up to the highest power ratings manufactured by ABB have been subject to such testing.

A comprehensive treatise on mechanical forces in transformers during short circuit conditions is given in [6] 17.2 page 200.

All in all, this illustrates that to design and manufacture reliable large power transformers for high voltages in an economical and competitive way requires considerable resources and long experience.

ABB manufactures large power transformers for system voltages up to and including 800 kV and with the highest power ratings demanded by the market.

Even a transformer for a UHV test line of 1785 kV system voltage has been delivered.

Power rating limitations

When transporting the transformer from the factory to the site limitations in the transport profile might be encountered, which restrict the power rating of the transformer. The transformer height is often the limiting dimension. In that case the transformer designer has the possibility to reduce the height by choosing a 5-limb core instead of a 3-limb core. See section 6.1 page 77.

2.4.1. Generator step up transformers

These transformers take the voltage from the generator voltage level up to the transmission voltage level, which may go up to 800 kV system voltage. Such transformers are usually Ynd-connected. There are several reasons for connecting the low voltage winding in delta instead of star:

- the delta-connected winding keeps the zero sequence impedance of the transformer reasonably low;
- for large transformers the line current on the low voltage side is very high. In a delta-connected winding the current through the winding is equal to the line current divided by $\sqrt{3}$, which makes the winding work in the factory easier with a correspondingly smaller bundle of winding conductors.

The high voltage neutral is in most cases solidly earthed and the insulation in the high voltage winding is graded, that is, the insulation level in the neutral is lower than in the phase end of the winding.

Full utilisation of the generator's ability to supply active power to the system, and in addition, its ability to supply reactive power to the system and absorb reactive power from the system, requires that four transformer characteristics should be selected on the base of a thorough study. These four characteristics are:

- The short circuit impedance of the transformer;
- The secondary (high) voltage rating;
- The transformer MVA rating;
- The primary (low) voltage rating.

IEEE C57.116 – 1989 TM, IEEE guide for Transformers Directly Connected to Generators describes an analysis method for selection of these characteristics.

In order to ensure that the transformer does not restrict the exchange of reactive power between the generator and the power system it may be necessary to provide tappings in the high voltage winding of the transformer. These tappings are normally placed at the neutral end of the winding.

In underground hydro power stations the circuit breaker on the high voltage side is often located at a distance of several hundred metres from the transformer. The transformer and the circuit breaker are connected to each other by means of a cable. When energising the transformer from the high voltage side, high frequency oscillations arise on the terminals due to travelling waves that are reflected back and forth in the cable. See [1] Section 17.2 page 200.

Every transformer winding has a number of resonance frequencies, which can be identified by means of measurements in the factory. At some of these frequencies high internal overvoltages may arise if the frequency of the oscillations that occur during energisation coincide with one of the critical resonance frequencies of the transformer winding. This potentially dangerous situation can be avoided by energising the transformer from the generator side and then synchronising the generator with the system by means of the circuit breaker at the high voltage side.

There may be a fixed connection between the transformer and the generator, or a circuit breaker may be situated in between.

When there is a fixed electrical connection, the generator and the transformer are inseparable and act as one unit. In case of failure on either side of the transformer, relays may quickly trigger the circuit breaker on the high voltage side of the transformer to disconnect the unit from the system. This sudden load rejection may cause higher voltage on the generator terminals and consequently to overexcitation of the transformer. The magnitude and duration of this overexcitation depend of the characteristics of the generator and its excitation system. The purchaser should inform the transformer supplier about the maximum magnitude and duration of this temporary overvoltage as early as possible in the project process and in any case in due time before the design of the transformer is finally determined.

Overvoltage protection of the low voltage winding of generator step-up transformers needs special consideration because of the often large difference in voltage and consequently insulation level on the two sides and the magnitude of transferred transient and temporary overvoltages from the high voltage to the low voltage side.

It is recommended that surge arresters be installed between each low voltage terminal and earth and also between terminals of different phases and, in addition, capacitors between phase terminals and earth. Typical capacitance that has been used is 0,25 μF.

The transferred overvoltages can be especially critical when the low voltage winding is disconnected from the generator.

In several cases bus ducts enclose each phase conductor between the transformer and the generator in order to minimise the risk of short circuits between the phase conductors. For large generator step-up transformers the current in these conductors are very high with accompanying strong magnetic fields, which may cause unanticipated circulating currents in transformer tanks and covers, bushings and in the bus ducts themselves. The losses caused by these unanticipated currents result in overheating if corrective measures are not included in the design. The overheating of the transformer components depends upon the method of terminating the bus ducts at the transformer end. In order to mitigate the heating problem it is suggested that design coordination meetings be arranged between the bus duct supplier, the transformer manufacturer and the purchaser prior to the design of the bus duct.

Figure 2-5

Figure 2-5 shows an example of a large three-phase generator step up transformer. The rated power is 1100 MVA and the voltage ratio 345/19 kV. In this case the transformer is made as a shell-type.

2.4.2. Step-down transformers

Step-down transformers take the voltage down from the transmission voltage to an appropriate distribution voltage. The power rating of step-down transformers may range up to power rating of the transmission line. They frequently are equipped to vary the turn ratio ±15% in steps of 1-1,5% by means of an on-load tap changer. (See section 7.3.2 page 100).

The electricity supply system often has several different distribution voltage levels as the supply system branches out before the voltage is finally taken down to the domestic consumption voltage level, see 2.1 page 7.

Between these different distribution voltage levels there are step-down transformers with decreasing power rating as the system approaches the consumer. They are mostly regulating transformers, and their turn ratio is often controlled by means of voltage regulation relays in order to keep the output voltage constant. However, in mesh networks with relatively strong systems on both sides of the transformer changing the turn ratio of the transformer may not essentially change the voltage, only influence the exchange of reactive power between the two sides of the transformer. Experience shows that the voltage regulation relay in such situations sends the on-load tap changer to its end position without any noticeable change in the voltage on the secondary side of the transformer.

2.4.3. System intertie transformers

System intertie transformers connect transmission systems with different voltages together with the purpose that active as well as reactive power can be exchanged between the systems.

The power rating of such transformers may be quite high, for example 1000 MVA, and they are sometimes made auto-connected in order facilitate the transport from the factory to the site by the lower weight and physical dimensions. In addition the manufacturing cost will be lower compared to a transformer with separate windings.

The turn ratio of such transformers is sometimes fixed, while tappings may be provided in other cases. The different tappings may not noticeably influence the voltage on either side of the transformer. However, the tappings provide the ability to influence the exchange of reactive power between the systems.