Disconnecting Circuit Breakers
Application Guide
Introduction

| ABB Disconnecting Circuit Breakers |
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Disconnecting Circuit Breaker
Integration of a circuit breaker and a disconnector into one unit

Development in circuit breaker technology has led to significant decreases in maintenance and increases in reliability for circuit breakers. Maintenance intervals, requiring de-energizing of the primary circuit, of modern SF$_6$ circuit breakers are 15 years or more. At the same time, development of open air disconnectors has focused on cost reductions by optimizing the material used, and has not produced any significant improvements in maintenance requirements and reliability. Reduced maintenance of circuit breakers compared to open air disconnectors led to the development of the disconnecting circuit breaker, which incorporates the disconnecting function in the open gap of the circuit breaker contacts.

The development program at ABB is strongly focused on providing added value for our customers. The disconnecting circuit breaker is an example of this. ABB pioneered the first-ever disconnecting circuit breaker installation in 1999, and it was based on a need by one of our customers.

The disconnecting circuit breaker enables smarter, safer and greener substations due to the removal of conventional disconnectors. Substations equipped with disconnecting circuit breakers have higher availability in supplying power, they require less maintenance and space, and CO$_2$ emissions are greatly reduced in comparison to conventional substations.

ABB has a comprehensive portfolio of disconnecting circuit breakers, from 72.5 kV all the way up to 550 kV, and the portfolio is being continuously improved. ABB has a solid track record of delivering disconnecting circuit breakers to the harshest environments in the world, which is a proof of ABB’s technological edge.
Compact air insulated HV switchgear with Disconnecting Circuit Breakers

ABB has a century of experience in building substations for high voltage systems. Design and manufacturing of the switchgear have been constantly refined over the years. This permits substations to be built with minimized needs for maintenance and space, low failure rates, increased safety and low life cycle costs. The disconnecting circuit breaker is a part of this continuous development.

Bracket for current transformers

A DCB uses a circuit breaker support structure on which a earthing switch and current transformer can also be mounted. Furthermore, a complete prefabricated busbar structure - with the necessary primary electrical connections can be also included.

Line Entrance Module

A separate structure called a Line Entrance Module (LEM) is available for supporting apparatus such as voltage transformers, surge arresters and earthing switches.

The breaker structure together with an LEM, are normally the only structures needed to install the HV-apparatus in a switchgear bay built with a DCB.

Primary switchgear apparatus

ABB offers a complete range of primary apparatus for use in Air Insulated Switchgear. Additional information can be found in the Application and Buyer’s Guide for each product according to the table below.

<table>
<thead>
<tr>
<th>Product</th>
<th>Buyers Guide</th>
<th>Application Guide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live Tank Circuit Breakers</td>
<td>1HSM 9543 22-00en</td>
<td>1HSM 9543 23-02en</td>
</tr>
<tr>
<td>Outdoor Instrument Transformers</td>
<td>1HSM 9543 42-00en</td>
<td>1HSM 9543 40-00en</td>
</tr>
<tr>
<td>Surge Arresters</td>
<td>1HSM 9543 12-00en</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>DCB LTB 72.5</th>
<th>DCB LTB 145</th>
<th>DCB HPL 170-245</th>
<th>DCB HPL 362 - 420</th>
<th>DCB HPL 550</th>
<th>DCB LTB 72.5 with CT</th>
<th>DCB LTB 145 with CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage, kV</td>
<td>72.5</td>
<td>145</td>
<td>170 - 245</td>
<td>362 - 420</td>
<td>550</td>
<td>72.5</td>
<td>145</td>
</tr>
<tr>
<td>Rated current, A</td>
<td>3150</td>
<td>3150</td>
<td>4000</td>
<td>4000</td>
<td>4000</td>
<td>3150</td>
<td>3150</td>
</tr>
<tr>
<td>Circuit breaking current, kA</td>
<td>40</td>
<td>40</td>
<td>50</td>
<td>63</td>
<td>63</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Rated frequency, Hz</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
</tr>
</tbody>
</table>
Symbols
In this document the following symbols are used in single line diagrams.

- Circuit breaker
- Disconnector
- Disconnecting Circuit Breaker
- Voltage transformer
- Current transformer
- Surge arrester

SCADA symbols

<table>
<thead>
<tr>
<th>SUBSTATION1</th>
<th>SUBSTATION2</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAD01</td>
<td>QC001</td>
</tr>
<tr>
<td>QA001</td>
<td>QC002</td>
</tr>
<tr>
<td>Unlocked</td>
<td>QC001</td>
</tr>
<tr>
<td></td>
<td>QC002</td>
</tr>
</tbody>
</table>

Presentation of DCB in HMI
A new graphic symbol for drawings and illustration has been adopted and introduced in IEC 60617; see the figure below. Although here is no standard for representation of DCB in HMI, we recommend that the following dynamic illustration be used. The dynamic symbols must be able to demonstrate the different operation modes or sequences for the DCB;

Abbreviations
In this document abbreviations according to the list below are used.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB</td>
<td>Circuit Breaker</td>
</tr>
<tr>
<td>DCB</td>
<td>Disconnecting Circuit Breaker</td>
</tr>
<tr>
<td>DS</td>
<td>Disconnecting Switch</td>
</tr>
<tr>
<td>ES</td>
<td>Earthing Switch/Grounding Switch</td>
</tr>
<tr>
<td>SA</td>
<td>Surge Arrester</td>
</tr>
<tr>
<td>CT</td>
<td>Current Transformer</td>
</tr>
<tr>
<td>CVT</td>
<td>Capacitor Voltage Transformer</td>
</tr>
<tr>
<td>VT</td>
<td>Voltage Transformer</td>
</tr>
<tr>
<td>PI</td>
<td>Post Insulator</td>
</tr>
<tr>
<td>BB</td>
<td>Busbar</td>
</tr>
<tr>
<td>PT</td>
<td>Power Transformer</td>
</tr>
<tr>
<td>AIS</td>
<td>Air Insulated Switchgear</td>
</tr>
<tr>
<td>GIS</td>
<td>Gas Insulated Switchgear</td>
</tr>
<tr>
<td>SF6</td>
<td>Sulphur hexafluoride gas</td>
</tr>
<tr>
<td>OHL</td>
<td>Over-head Line</td>
</tr>
<tr>
<td>CL</td>
<td>Cable Line</td>
</tr>
<tr>
<td>SLD</td>
<td>Single Line Diagram</td>
</tr>
<tr>
<td>LEM</td>
<td>Line Entrance Module</td>
</tr>
<tr>
<td>CCC</td>
<td>Central Control Cabinet</td>
</tr>
<tr>
<td>MDF/DL</td>
<td>Manual Disconnecting Facility/Disconnecting Link</td>
</tr>
<tr>
<td>IED</td>
<td>Intelligent Electronic Device</td>
</tr>
<tr>
<td>MV</td>
<td>Medium Voltage</td>
</tr>
<tr>
<td>HV</td>
<td>High Voltage</td>
</tr>
<tr>
<td>S/S</td>
<td>Substation</td>
</tr>
<tr>
<td>LCA</td>
<td>Life Cycle Assessment</td>
</tr>
<tr>
<td>LCC</td>
<td>Life Cycle Cost</td>
</tr>
</tbody>
</table>
**Background**

Development in circuit breaker technology has led to significant decreases in maintenance and increases in reliability for circuit breakers. Maintenance intervals, requiring de-energizing of the primary circuit, of modern SF₆ circuit breakers are 15 years or more. At the same time, development of open air disconnectors has focused on cost reductions by optimizing the material used, and has not produced any significant improvements in maintenance requirements and reliability. The maintenance interval for the main contacts on open-air disconnectors is about two to six years, differing between different users and depending on the amount of pollution due to industrial activities and/or “natural” pollutants such as sand or salt.

The reliability of circuit breakers has increased due to evolution of primary breaking technology, from air blast, oil minimum and SF₆ dual-pressure circuit breakers into today’s SF₆ single-pressure circuit breakers. At the same time, the number of breaking units per pole has been reduced, and live tank circuit breakers up to 300 kV are now available with one breaking unit per pole. Removal of grading capacitors for live tank circuit breakers with two breaking units per pole has further simplified the primary circuit and thus decreased the failure rate. Circuit breakers up to 550 kV are presently available without grading capacitors, enabling the development of disconnecting circuit breakers up to this voltage.

Operating mechanisms for circuit breakers have also improved. Since going from pneumatic or hydraulic mechanisms to spring or motorized type mechanisms, maintenance requirements and failure rates have decreased.

In the past, the design principle when building substations was to “surround” circuit breakers with disconnectors to enable frequent maintenance of the circuit breakers. Due to the large reduction in failure and maintenance rates for circuit breakers, the disconnecting function is now more appropriate for maintenance of overhead lines, power transformers, etc. Reduced maintenance of circuit breakers compared to that of open air disconnectors, led to the development of the
disconnecting circuit breaker in close collaboration with some of our major customers. The disconnecting circuit breaker combines the switching and disconnecting functions into one device, thus reducing the substation footprint and increasing availability. The first installation of a disconnecting circuit breaker was in the year 2000. Disconnecting circuit breakers are now available from 72.5 kV to 550 kV and installed in more than 30 countries around the world.

**Design**

In a disconnecting circuit breaker, the normal interrupter contacts also provide the disconnecting function when in the open position. The contact system is similar to that of a normal circuit breaker, and there are no extra contacts or linkage systems. The disconnecting circuit breaker is equipped with silicone rubber insulators with hydrophobic properties, i.e. any water on the surface will form droplets. As a result, they provide excellent performance in polluted environments and any leakage current across the poles in the open position is minimized.

The main advantage of the disconnecting circuit breaker compared to a conventional disconnector is that the electrical contacts are enclosed in SF₆ gas, as in GIS substations, and thereby protected from the effects of ambient conditions, including the effects of pollution. The protected environment provides improved reliability and prolonged intervals between de-energization for maintenance of the disconnecting circuit breaker.

An important aspect of the disconnecting circuit breaker is its ability to provide safe working conditions during maintenance and repair work in substations. When the disconnecting circuit breaker is used to isolate other equipment, it needs to be locked in the open position in a fail-safe way. This important aspect has been considered in the design and specification of the disconnecting circuit breaker. The locking consists of electrical and mechanical locking of the operating mechanism, as well as mechanical locking of the main linkage system for the breaker pole.

A disconnecting circuit breaker has to fulfill both applicable circuit breaker standards and disconnector standards. A specific standard for disconnecting circuit breakers, IEC 62271-108, was issued in 2005.
What is a Disconnecting Circuit Breaker?

Standards

IEC (International Electrotechnical Commission) has issued a family of standards, IEC 62271, for high-voltage switchgear. The specific requirements for disconnecting circuit breakers are given in IEC 62271-108. In addition, the disconnecting circuit breaker must fulfill the requirements of both the circuit breaker standard IEC 62271-100, and relevant parts of the disconnector standard IEC 62271-102. In turn, IEC 62271-100 and IEC 62271-102 refer extensively to the common requirements stipulated in IEC 62271-1.

IEC standards applicable for disconnecting circuit breakers

<table>
<thead>
<tr>
<th>Part</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1</td>
<td>Common specifications</td>
</tr>
<tr>
<td>-100</td>
<td>High-voltage alternating current circuit breakers</td>
</tr>
<tr>
<td>-102</td>
<td>Alternating current disconnectors and earthing switches</td>
</tr>
<tr>
<td>-108</td>
<td>High-voltage alternating current disconnecting circuit breakers for</td>
</tr>
<tr>
<td></td>
<td>rated voltages of 72.5 kV and above</td>
</tr>
</tbody>
</table>

Important sections in IEC 62271-108 specify how to interlock and secure a disconnecting circuit breaker against unintended operation, and also how to verify the dielectric withstand performance after an extended period in service.

Indication of position

The disconnector standard IEC62271-102 includes the requirements that it shall be possible to know the operating position, whether open or closed. Two alternative ways of meeting this requirement are given:

- The isolating distance or gap is visible
- The position of each movable contact ensuring the isolating distance or gap is indicated by a reliable visual position indicating device

For disconnecting circuit breakers the second method is applied, with a reliable visual position indicating device. The rigidity of the kinematic chain between the main contacts and the indicating device is verified by a designated type test.

Type tests

Before a new disconnecting circuit breaker type is released, numerous tests are performed to verify that it complies with the requirements of the IEC standards. Once the design of the disconnecting circuit breaker has been finalized, type tests are performed on some of the first manufactured units. Type tests may be performed at the testing facilities of the manufacturer or at other (independent) laboratories.

A disconnecting circuit breaker must pass the relevant type tests required for both circuit breakers and disconnectors, as stipulated in IEC 62271-108.

A disconnecting circuit breaker has two different functions — switching current in its function as a circuit breaker, and isolation in its function as a disconnector. The main contacts, the hollow insulator in which they are located and the SF₆ gas surrounding the contacts may be affected by the mechanical and electrical switching operations performed. It is therefore essential to verify that the design fulfills the dielectric withstand requirements for the isolating distance, applicable for
disconnectors, not only when new but also after an extended period in service. This requirement is verified by the combined function test, specified in IEC 62271-108. In this test, the dielectric withstand capability across the isolating distance is demonstrated after a mechanical operation test, as well as after a specified short-circuit test duty.

The combined function test consists of one part limited to the mechanical function, and one part limited to the electrical function. These two parts may be performed either separately or together in one sequence. The mechanical combined function test is performed with the appropriate number of operations for mechanical endurance class M1 or M2.

**Routine tests**

Routine tests are performed on each disconnecting circuit breaker manufactured to reveal any faults in materials or assembly.

**Quality control**

ABB AB, High Voltage Products in Ludvika has an advanced quality management system for development, design, manufacturing, testing, sales and after sales service, as well as for environmental standards, and is certified by Bureau Veritas for ISO 9001 and ISO 14001.
Designing safe substations
Substations without visible gaps

Substations without visible gaps
Over the years the visible gap provided by disconnectors has been used as an indication of safety when working in AIS substations. In GIS substations, and with all medium voltage switchgear, there was no need for a visible gap from the beginning. A reliable indication device (assured by IEC tests) has been used instead for disconnectors and earthing switches.

A visible gap itself does not provide sufficient safety to start work on high voltage equipment. Not until an earth is connected, can work on high voltage equipment be carried out.

When the disconnecting circuit breaker is locked in its open position, it has the same function and dielectric withstand as a traditional disconnector. The safety needed to start work on high voltage equipment is still achieved when the **visible earthing switch** is closed.

To further enhance safety, it is always recommended to conduct all operations remotely. Substations with disconnecting circuit breakers utilize remotely operated visible earthing switches for safety measures, rather than the visible gap and portable earthing switches used in conventional solutions. After a sequence of operations (open DCBs, lock DCBs, close earthing switches), the substation personnel can enter the already earthed switchyard to padlock all equipment before the next work permit is submitted.

Safety distances
IEC and other standards prescribe distances in switchgear. Those standard values can sometimes be raised by the customer due to local conditions.

Special attention must be paid to the distance “to nearest live part”, also called section clearance. This distance must be established between all live parts and the location in the switchgear where work will be performed.

The table shows example values that must always be coordinated with the demands of the actual installation.

<table>
<thead>
<tr>
<th>Example values for distances (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>72.5 kV</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Lowest insulator base to earth</td>
</tr>
<tr>
<td>Earth and lowest live part</td>
</tr>
<tr>
<td>Between phases</td>
</tr>
<tr>
<td>Phase to earth</td>
</tr>
<tr>
<td>Transport way profile</td>
</tr>
<tr>
<td>To nearest live part</td>
</tr>
</tbody>
</table>
Earthing switches

Where to place earthing switches
Depending on the configuration and voltage level in the substation, the position of the earthing switches differs. Regardless of substation configuration, it is recommended that an earthing switch be placed on each busbar in the substation.

For single-busbar applications, the earthing switch is normally installed on the same structure as the DCB, and the fixed contact of the earthing switch is installed on the lower connection flange on the disconnecting circuit breaker (see Figure 1).

In systems where the object is fed from two directions, e.g. double-breaker or breaker-and-a-half systems, it is more practical to use a freestanding earthing switch at the common connection point to the object (see Figures 2 and 3). This is because the purpose of the earthing switch is to earth the connected object (line/transformer, etc.) and not the circuit breaker or other high voltage equipment.

Remote operation of the earthing switches is recommended and a motorized earthing switch should thus be used.
The operation sequence allowed in the substation when utilizing disconnecting circuit breakers is according to the same principles as for a conventional substation. See the example below for assurance that an object is not unintentionally earthed.

Once mechanical locking of disconnecting circuit breakers has been carried out, the output signal “disconnecting circuit breaker locked in open position” is sent to the interlocking system. As soon as all other paths feeding the object to be earthed are also disconnected, and the primary voltage at this point is zero (checked through voltage transformer to ensure that the remote line end is open), the interlocking system will produce a release signal that enables the earthing switch to be closed. Normal safety actions, such as padlocking and labeling of the closed earthing switch, are carried out in the usual way.
Interlocking of disconnecting circuit breakers

**Electrical interlocking**

Besides the mechanical locking of an open DCB, electrical interlockings shall be applied as:

<p>| DCB closed | DCB can operate/perform switching. Locking inactivated and interlocked. Earthing switch open and interlocked. |</p>
<table>
<thead>
<tr>
<th>DCB open and locking not activated</th>
<th>DCB can operate/perform switching. Locking device can be operated. Earthing switch open and interlocked.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCB open and locking activated</td>
<td>DCB operation locked and interlocked. Locking device can be operated. Earthing switch can be operated.</td>
</tr>
<tr>
<td>Earthing switch closed</td>
<td>DCB operation locked and interlocked. Locking device interlocked. Earthing switch can be operated.</td>
</tr>
</tbody>
</table>

Principles of the electrical interlocking system, disconnecting circuit breaker locked in open position. Earthing switch in open position.
Availability and reliability

**General information**

**Availability and reliability**
In today’s electrical transmission and distribution grids, the biggest concern is in dealing with outages, thus maximizing the capability to transmit power to end-customers. Outages are normally due to maintenance but could also be caused by repair work after failures.

The way to maximize the power flow is to use equipment in the substation with low maintenance requirements, as well as suitable substation configurations.

Another major obstacle is in avoiding any blackouts for power consumers, or loss of connection to generating power stations. Such events are entirely related to unplanned activities due to a failure of some kind. The “quality” of a certain substation in this respect is often expressed as reliability, or how failure tolerant it may be. Reliability, such as for an outgoing bay in a substation, is the probability of failure-free power supply at that point during a specified period of time. Unreliability may be expressed as the expected number of interruptions per year.

**Improved availability with DCB**

The availability of an outgoing bay in a substation, is the fraction of time that electrical power is available at that point.

A typical power path through a substation can be divided into three main parts: line, power transformer and switchgear. Lines and power transformers have relatively high maintenance requirements. They constitute the chief cause for maintenance outages in substations supplied by single radial lines, or with only a single transformer. In such cases, maintenance of switchgear is of secondary importance. On the contrary, if power can be supplied from more than one direction and the substation is equipped with parallel transformers, the overall unavailability of the substation, due to maintenance, may be directly related to the switchgear and the substation configuration. Decisive factors are then the HV equipment used, as well as the arrangement (single-line diagram) of the substation.

The chief reason for unavailability of a certain part of a substation is maintenance. Unavailability, i.e. the fraction of time that electric power is not available, is normally expressed in hours per year.

In the past, circuit breakers were mechanically and electrically complex and therefore required considerable maintenance. The focus was on how to isolate the circuit breaker for maintenance and keeping the other parts of the substation in service. The substations were accordingly built with circuit breakers surrounded by several disconnectors enable circuit breaker to be isolated and maintained. Now when modern circuit breakers require less maintenance than conventional disconnectors, substation availability is improved when conventional disconnectors are removed and disconnecting circuit breakers are used.

**Improved reliability with DCB**

Reliability is the probability of failure-free power supply at a certain point during a specified period of time.

From the above statement it is clear that only failure frequency, not maintenance in the substation, is taken into consideration when looking at reliability. Failure or unreliability of any equipment in the substation is usually considered as the most costly substation event, as it cannot be planned for in advance.

The concept of the disconnecting circuit breaker is to eliminate conventional disconnectors and simplify substation design. This minimizes the probability of a failure in a substation. Substations equipped with disconnecting circuit breakers can be built in a more simplified arrangement than substations with conventional equipment and still achieve higher reliability.

For important substations, it may not be acceptable from a system security perspective to risk losing the whole substation in the event of a primary fault. To make a substation “immune” against busbar faults and to minimize the disturbance in the event of a primary fault, a breaker-and-a-half or double breaker arrangement is commonly used.
Disconnecting link

Sometimes it can be practical to disconnect a unit from the busbar or the line during maintenance or repair. This is not a special demand for solutions with disconnecting circuit breakers, but it has been emphasized as a tool to further increase availability.

A disconnecting link, is a point in the substation prepared for fast opening of the primary connection, between disconnector for example, or in this case, a disconnecting circuit breaker and the busbar.

When a disconnecting circuit breaker is isolated in this way, the other parts of the substation may be re-energized during work on the disconnecting circuit breaker itself. This increases the overall availability of the substation.

The disconnecting link consists of standard clamps and a wire or tube. The connection points for the disconnecting link are arranged so that when the disconnecting link is removed, there are necessary safety distances between the isolated equipment and the busbar or line. The distance shall fulfill specific requirements in the form of section clearance. The figures illustrate with dots, where section clearance is applied in different substation arrangements.

Removal and reconnection of a disconnecting link in a 420 kV substation is estimated to take less than one hour for each operation.

An important factor is that a disconnecting link is not to be compared with a disconnector since it is maintenance free and is intended to be used only on rare occasions, typically once or twice during the lifetime of the substation.
Availability and reliability
Improving availability and reliability in a 145 kV substation

As an example, a comparison is made between a conventional double busbar substation versus a sectionalized single busbar arrangement, equipped with disconnecting circuit breakers and disconnecting links. As the conventional double bus single breaker and DCB sectionalized single breaker are connected in the same way during normal service conditions, and busbar switching is typically only carried out due to scheduled disconnector maintenance, this is a very good comparison to make. Assumed maintenance intervals are five years for open air disconnectors and 15 years for circuit breakers and disconnecting circuit breakers.

The comparison involves:

- 4 – Incoming OH lines
- 2 – Power transformers
- 1 – Bus coupler

Introduction of the disconnecting circuit breakers reduces the average unavailability due to maintenance for a single bay in the substation from 3.07 to 1.2 hours per year. The comparison proves that the reliability of a single bay in the substation will increase, thus decreasing the failure outage duration from 0.17 to 0.15 hours per year.

<table>
<thead>
<tr>
<th>Maintenance outage 145 kV</th>
<th>Failure outage 145 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit breakers and disconnectors</td>
<td>3.07</td>
</tr>
<tr>
<td>Disconnecting circuit breakers</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Conventional double bus single breaker substation with disconnectors

Sectionalized single bus substation with disconnecting circuit breaker

Disconnecting Circuit Breaker

Disconnecting link, to be used during maintenance or in a rare case of failure of disconnecting circuit breaker
Improving the availability and reliability in a 420 kV substation

An availability comparison is made between a conventional 420 kV breaker-and-a-half arrangement with conventional equipment and an arrangement of the same type using disconnecting circuit breakers and disconnecting links.

The comparison involves:

- 3 – Incoming OH lines
- 2 – Power transformers
- 1 – Shunt reactor

Introduction of the disconnecting circuit breakers reduces the average unavailability due to maintenance for a single bay in a 420 kV substation from 4.8 to 0.27 hours per year or 94% per year. The reliability of the substation will increase when equipped with disconnecting circuit breakers, hence decreasing failure outage from 0.13 to 0.04 hours per year or 69% per year.

Failure frequency input is taken from international statistical sources such as CIGRE, which gathers information from actual high voltage equipment in service. Since the disconnecting circuit breaker is very similar to a conventional circuit breaker, failure statistics are assumed to be the same for circuit breakers and disconnecting circuit breakers.
The development of the disconnecting circuit breaker has led to the integration of conventional circuit breakers and disconnectors into a single unit. The benefit of combining the two functions is that it enables the required space for the substation to be significantly reduced.

**Width difference of a substation using disconnecting circuit breakers**

The figures above provide an approximation of the space requirement for one bay in single-busbar arrangements using conventional equipment (Figure 4a) and disconnecting circuit breakers (Figures 4b and 4c).

Disconnecting circuit breakers can be used in most traditional substation configurations, and directly replace conventional CB/DS arrangements, thus minimizing the area needed for the substation.

Conventional substations normally require more space between the phases in the bays compared to disconnecting circuit breaker substation. This is due to movement of the disconnector arms.

In the case of a 420 kV breaker-and-a-half substation, the reduction in width is approximately 17%.
Space comparison in a 145 kV substation

Comparing the space requirements for a 145 kV substation using the same example from the chapter “Availability and reliability”, the following space reduction is achieved. See the figures below for single-line diagrams with layout drawings.

It can be concluded that by building a 145 kV substation with disconnecting circuit breakers instead of conventional equipment, the space requirements for the outdoor switch-yard is reduced from 4,200 m² to 2,500 m², which is a reduction of more than 40%. A disconnecting circuit breaker solution can also facilitate extension of the substation with one or two bays on either side of the transformer without using more space than a conventional solution with four overhead lines and two power transformers.

Disconnecting Circuit Breaker
Disconnecting link, to be used during maintenance or in a rare case of failure of disconnecting circuit breaker
Saving space with DCB
Space comparison in a 420 kV substation

Comparing the space requirements for a 420 kV substation using the same example from the chapter “Availability and reliability”, the following space reduction is achieved. See the figures below for single-line diagrams with layout drawings.

The conclusion when implementing a disconnecting circuit breaker in a 420 kV breaker-and-a-half arrangement is that a space reduction is achieved from 11,500 m² to 6,200 m², which is approximately 50% when compared to a conventional solution.

Space requirements for a conventional substation with circuit breakers and disconnectors

Space requirements for a substation with disconnecting circuit breakers (Space saving 46%)

Disconnecting Circuit Breaker

Disconnecting link, to be used during maintenance or in a rare case of failure of disconnecting circuit breaker
ABB has a clear commitment to decreasing the environmental impact caused by designed and manufactured systems and apparatus. We thus hold certification in compliance with environmental management systems ISO 14001 and ISO 14025. Minimized environmental impact during the development of the disconnecting circuit breaker has consequently been an important consideration. Life cycle assessment (LCA) procedures were applied to optimize the design, and checklists used to identify potential sustainability risks.

Use of disconnecting circuit breakers reduces the land area required for an air insulated substation and reduces material usage. The secondary system in the substation is simplified when interlocking functions between conventional disconnectors and circuit breakers are no longer required. In addition, power losses related to conventional disconnectors are avoided.

Use of raw materials
As the number of primary apparatus is decreased compared to conventional solutions, the total use of raw materials is significantly reduced. This refers to all kinds of material that are normally used in switchgear apparatus, such as steel, aluminum, copper, plastic, oil, etc.

Number of foundations — use of concrete
The number of foundations required for substations with disconnecting circuit breakers is significantly lower than for conventional switchgear as the number of primary apparatus is less. In addition, apparatus can be mounted on shared structures, which further decreases the number of foundations. Typically, a substation with disconnecting circuit breakers needs only half or less of the number of foundations compared to a conventional substation.

SF₆ gas
Disconnecting circuit breakers utilize SF₆ (sulfur hexafluoride) gas for insulation and arc quenching purposes in the same way as normal circuit breakers. However, SF₆ contributes to the greenhouse effect and must therefore be handled with caution.

The live tank design of the disconnecting circuit breaker minimizes the amount of gas used compared to alternative technologies. Any gas leakage during operation is also minimized by means of sealing systems using double O-rings for static seals and double X-rings for dynamic seals. High and low temperature tests have shown that the relative SF₆ leakage rate stays well below the strict IEC requirement of 0.5% per year for closed pressure systems, even under severe environmental conditions. The low gas volume together with the low leakage rate subsequently leads to minimized SF₆ emissions into the atmosphere. Furthermore, ABB has well-documented routines for handling SF₆, from production of the apparatus to removing it from service.

As illustrated by the examples on the following pages of life cycle assessment (LCA) calculations, the equivalent global warming potential (amount of CO₂ released into the atmosphere) is dominated by electric power losses during service life and not by SF₆ leakage.

Replacing SF₆ gas with CO₂ gas
Another groundbreaking technology is arc quenching by using CO₂ instead of SF₆, which completely removes the use of SF₆ in disconnecting circuit breakers up to 84 kV.

The graph below shows a comparison of life cycle environmental impact of ABB’s new LTA CO₂ circuit breaker with ABB’s LTB SF₆ circuit breaker considering service life of 30 years. The points below elaborate how the LTA technology has evolved for reducing environment impact in each of the three life cycle phases (design and manufacturing, service and scrapping).
Environmental benefits
LCA study, 145 kV

LCA study for 145 kV disconnecting circuit breaker with earthing switch
An LCA study was made for a 145 kV disconnecting circuit breaker, including the operating mechanism, earthing switch and support structure. The study took into consideration the environmental impact of the entire life cycle, and fulfilled the requirements of ISO 14040.

It was based on the following assumptions:

- 40 year life span
- Electrical losses for 50% of rated normal current, i.e. 1575 A per phase
- Three-pole operated disconnecting circuit breaker, resistance 32 μΩ/pole, heater 70 W continuous, plus 70 W thermostat controlled 50% of time

Several different environmental impact categories may be considered in LCA studies, such as acidification, ozone depletion and global warming. In the present case, evaluation was made with regard to the global warming potential (GWP). This is generally the dominating impact category for products consuming energy during their service life. The result is expressed in kg CO₂ equivalents.

The impact from electric energy consumption is based on a mix of power generation systems relevant for the OECD countries, and considers the LCA perspective: 0.6265 kg CO₂ per kWh.

As shown in the figure, electric energy consumption during the usage phase contributes most to the global warming potential. Resistive losses in the main circuit are responsible for 70% of this energy consumption. The rest is shared by the thermostat-controlled heater (10%) and the anti-condensation heater (20%) in the operating mechanism. It was assumed that the thermostat controlled heater was connected during half of the usage phase.

The contribution during the usage phase related to SF₆ leakage into the atmosphere is less than 10% of the total. This is a result of the small gas volume and low relative leakage rate of the live tank design. The contribution was calculated assuming a relative SF₆ leakage rate of 0.1% per year, which is typical for this type of disconnecting circuit breaker. At end-of-life, it was assumed that 1% of the gas is lost, while the rest is recycled.
LCA study, 245 kV

LCA study of three 245 kV substation alternatives
LCA assessment was carried out for three different types of 245 kV substations. All three variants were dimensioned to fulfill the conditions of an actual substation at a specific site:

- Five overhead lines, with fixed positions
- One power transformer with fixed position and connecting to an adjacent 420 kV substation

Conventional AIS substation (Type 1)
Double busbar conventional AIS substation, according to the following single-line diagram:

Indoor GIS substation (Type 2)
Indoor GIS substation, with the same single-line diagram as a conventional AIS substation. In the LCA, the required “external” connections from the GIS to the actual positions of the power transformer and OH lines were included. These external AIS connections added up to a total of 240 m. The following figure shows, as an example, the situation for the transformer bay:

AIS substation with disconnecting circuit breakers (Type 3)
This substation had a double-breaker configuration, which provides even higher flexibility and reliability than a double-busbar configuration.

The number of disconnecting circuit breakers in this configuration is 12, as compared to 7 circuit breakers in the double-busbar single-breaker configurations.

The main input parameters for the LCA analysis were:

- 30 year lifetime
- SF6 leakage rate 0.1% per year, for both AIS and GIS
- Two load current scenarios were used:
  - Scenario A: 80% of time at 25% of 3150 A, and 20% of time at 40% of 3150 A.
  - Scenario B: 80% of time at 40% of 3150 A, and 20% of time at 50% of 3150 A.
- The impact from electric energy consumption is based on a mix of power generation systems relevant for 25 European Union (EU) countries, and considers the LCA perspective: 0.5773 kg CO2 per kWh.
- The losses in the power transformer were not included

The main results of the study – the equivalent CO2 emissions are shown in the following figure:

The major conclusions of the study are:

- The lowest environmental impact is caused by the AIS substation with disconnecting circuit breakers (Type 3)
- The largest part of the environmental impact is caused by the electrical losses during service life

It should be kept clearly in mind that the results depend to a high degree on the actual conditions, line lengths, etc in the substation. A different situation may well lead to different results.
Life Cycle Cost (LCC)
General information

The high voltage equipment in a substation will have a certain “up-front cost”, followed by a number of additional costs, which gradually build up during the lifetime of the equipment. In life cycle cost (LCC) calculations all these cost elements are considered, in order to give a relevant picture of the total lifetime cost. Such LCC calculations can be used as a powerful tool when comparing different substation solutions as early as the planning stage.

The following cost elements should be included in an LCC calculation for the high voltage equipment in a substation:

Initial cost
When the LCC analysis is directly focused on the HV equipment, the initial cost consists of the purchase cost for this equipment and associated costs for the foundations needed for erection of the equipment. Installation and commissioning costs should also be included.

It may also be feasible to use a wider perspective and include further cost elements, such as design and planning, project management, civil works for the substation, busbars and primary connections between the HV equipment, and also auxiliary cabling. Such costs will generally be lower for substation solutions with disconnecting circuit breakers than for conventional solutions due to less space and less equipment being required, as well as due to the use of partly predesigned solutions.

Maintenance costs
The maintenance cost during the lifetime of the equipment will depend on the maintenance intervals and on the maintenance time. Both visual inspections and scheduled maintenance should be included. The cost of complete overhaul of the equipment, after many years in service may also be included, as well as distance costs related to travel to the site.

The maintenance cost will depend on the hourly rates of the service staff. For simplified calculations, it may be assumed that current transformers, voltage transformers and surge arresters are maintenance free.

Repair costs
The repair costs will depend on the failure rates of the equipment, and on the repair times and cost of spare parts. Typical failure rates may be taken from statistics published by CIGRÉ, for example. Distance costs, related to travel to the site, should be included. The repair costs will depend on the hourly rates of the service staff, rental costs of cranes etc.

Costs of electrical losses
The main current leads to electrical losses both in the high voltage equipment and in the connections between them. The losses depend on the magnitude of the current, and a suitable, average current value should be used for the calculation. When different substation configurations are compared, the interconnections included in the comparison should be chosen in the same way, such as based on the length of a diameter in a breaker-and-a-half configuration. In addition to the main current losses, the energy consumption of heaters in the operating mechanisms of the circuit breakers, disconnecting circuit breakers and disconnectors should be included.

The maintenance costs, repair costs and costs of electrical losses will all build up gradually during the service life of the equipment. These costs should therefore be recalculated to present values using a suitable interest rate.

Two examples of LCC calculations are shown here, making comparisons between substation solutions with conventional circuit breakers and disconnectors, and with disconnecting circuit breakers.
LCC study of 145 kV single busbar substation

The life cycle cost (LCC) is calculated for a single 145 kV disconnecting circuit breaker, compared to an arrangement with a conventional circuit breaker surrounded by two disconnectors. For the conventional arrangement, the connections between the disconnectors and the circuit breaker are included (blue section in the figure).

Realistic costs are assumed for purchase of equipment, installation, maintenance and repair. A 30-year time span is used. Complete revision of the equipment is included, at the end of the time span. The electric losses are calculated with current of 1575 A, which is 50% of the rated current. Electrical losses in the heaters of the operating mechanisms are included. The cost of the electrical losses is based on 0.03 EUR per kWh.

The figure shows the costs as present values, based on a 5% annual interest rate. The initial cost (purchase plus installation costs) of the two alternatives is more or less equal, while the total cost is higher for the conventional alternative. This is due to considerably higher costs for both maintenance and electrical losses.

LCC comparison; Disconnecting circuit breaker versus conventional solution, single-bay 145 kV
The life cycle cost is calculated for the high voltage equipment of a 420 kV substation with a breaker-and-a-half configuration, and four diameters. Two alternatives are compared, one with disconnecting circuit breakers, and one with conventional circuit breakers and disconnectors. The costs associated with all high voltage equipment regarding the feeders and diameters are included, i.e. circuit breakers or disconnecting circuit breakers, disconnectors, earthing switches, current and voltage transformers, and surge arresters. As can be seen in the figures, it has been assumed that there are no disconnectors on the feeders. High voltage equipment directly connected to the busbars is not included. Connecting conductors in the diameters and between HV equipment connected to the feeders are included (blue and red sections in the figures).

Realistic costs are assumed for purchase of equipment, installation, maintenance and repair. A 30-year time span is used. Complete overhaul of the equipment is included, at the end of the time span. The electric losses are calculated with current of 2000 A, which is 50% of the rated current (flowing in the blue section of the feeders and diameters). Electric losses in the heaters of the operating mechanisms are included. The cost of the electrical losses are based on 0.05 EUR per kWh.

The figure shows the costs as present values, based on a 5% annual interest rate. The initial cost (purchase plus installation costs) for the alternative with disconnecting circuit breakers is slightly lower than for the conventional alternative with circuit breakers and disconnectors. The total cost is also lower, due to lower maintenance and repair costs, and also lower cost of electrical losses for the alternative with disconnecting circuit breakers.
Substation design
Single-line diagrams

Different substation configurations
When designing a new substation, a number of considerations need to be taken into account. One of those is the configuration illustrated by the single-line diagram (SLD). When preparing single line diagrams, the main goal is to create a solution suitable for the specific requirements of the substation. Many factors — such as the expected load, safety requirements, substation budget, surrounding power network, effects of power loss, availability and reliability requirements, etc. — influence the final decision.

Single-breaker configurations
Substations designed with only a single circuit breaker per object and several surrounding disconnectors are considered as maintenance-focused substations. Common for these are that the circuit breakers and sometimes disconnectors can easily be isolated without affecting the power flow in the busbar and when bypass disconnectors or a transfer bus is used, not the actual load on connected objects. Double-busbar single circuit breaker configurations are commonly used. Nonetheless, the load is divided in the substation as with a sectionalized single busbar and switching in the substation is mainly performed when busbar-adjacent disconnector maintenance is carried out. In such configurations, a line fault in combination with protection failure or a no-trip event on a circuit breaker would result in a loss of at least half the substation.

Examples of conventional and disconnecting circuit breaker single line diagrams for single circuit breaker configurations are shown on the following pages.

As stated for the above solutions with single-busbar configuration, maintenance of the busbar adjacent disconnectors takes the section or the entire substation out of service. To eliminate this problem double busbars were introduced, i.e. the main reason for double busbar systems is to allow disconnector maintenance without affecting the other objects in the substation.

Double-breaker configurations
Substations with the object of interest connected to two circuit breakers are considered to be failure- and maintenance focused substations. For example, a line failure in combination with a protection failure or no-trip event on a circuit breaker would only affect the object of interest and maximum one other object. That is the reason why these types of configurations are most commonly used in transmission grids and industries with very high availability and reliability requirements.

Another advantage of these configurations with two simultaneous feeder paths is that the object can be easily restored to service after a failure or maintenance of relevant equipment.

New possibilities with disconnecting circuit breakers
As shown earlier in the chapter “Availability and reliability”, modern SF₆ circuit breakers offer better maintenance and failure performance than disconnectors. That means that the traditional way of building substations with many busbar systems and disconnectors decreases availability instead of increasing it. Taking only the above into consideration, the best way to increase availability is to eliminate all disconnectors and only use circuit breakers. However, due to safety aspects, a disconnector function is necessary, which makes the disconnecting circuit breaker necessary for designing disconnector-free substations.

The disconnecting circuit breaker is suitable for use in substation configurations such as:

- Single busbar
- Sectionalized single busbar
- Double breaker
- Ring bus
- 1½ circuit breaker
- Combination configurations

If a double-busbar or transfer bus system is under consideration, it can preferably be replaced by a double-busbar, double-breaker system. In the following section some examples of the above will be illustrated.
Substation design
Single-busbar configurations

Single busbar
Single busbar is the simplest configuration and is preferably used in smaller substations with single line feed and lower voltages. In the single busbar configuration, all objects connect to the same busbar, making the substation small but vulnerable to failures and maintenance. If maintenance is required on any of the busbar-adjacent equipment, the entire substation must be taken out of service.

Conventional
With the conventional single busbar configuration, busbar disconnectors enable circuit breaker maintenance without de-energizing the busbar. Nonetheless maintenance of busbar-adjacent disconnectors takes the busbar out of service. As the busbar-adjacent disconnector presently requires more maintenance than conventional circuit breakers, the busbar availability is decreased compared to a disconnecting circuit breaker solution.

Disconnected Circuit Breaker
In the disconnecting circuit breaker solution, all disconnectors are removed; hence the maintenance frequency for the substation is decreased from approximately every five years to every fifteen years. Simplified interlocking schemes together with a smaller substation footprint and lower maintenance requirements will provide cost benefits in comparison to the conventional solution.

Single busbar with bypass disconnector
In a configuration with a single busbar and bypass disconnector, objects stay connected as in the single busbar configuration. The bypass disconnector was introduced to enable circuit breaker maintenance without losing the line. When the circuit breaker is in need of maintenance the line can be connected through the bypass disconnector to the busbar, hence the line will be connected without a breaker. If a line failure should occur in this situation, the entire substation would be taken out of service.

Conventional
Today’s bypass disconnectors require more maintenance than the circuit breakers they were supposed to eliminate maintenance outage from, hence line availability will decrease compared to a single busbar configuration. The added bypass disconnector will also deenergize the busbar, and hence the entire substation, during required maintenance.

Disconnected Circuit Breaker
The solution with disconnecting circuit breakers and bypass disconnectors is not applicable since no disconnectors are used. It is instead recommended to use a single busbar or sectionalized single busbar with disconnecting circuit breakers to improve substation availability.
Single busbar with transfer busbar
In the configuration with a single busbar and transfer busbar, the objects stay connected as in the single-busbar configuration. The single busbar with transfer busbar was introduced to enable circuit breaker maintenance without losing the object. During circuit breaker maintenance, the bus-coupler breaker is used as the line breaker for the bay where circuit breaker maintenance is performed. This solution has lost its purpose today because transfer disconnectors require more maintenance than circuit breakers, hence the object's availability will decrease compared to a single-busbar configuration.

Conventional
The advantage of a single busbar with transfer bus compared to a single busbar with a bypass disconnector is that maintenance of the transfer disconnector will not affect the main busbar as the bypass disconnector does. Nonetheless, as mentioned in the section above, a pure single-busbar solution will perform better than a single busbar with a transfer busbar.

Sectionalized single busbar
Sectionalized single busbar (also known as H-configuration) is normally used in distribution substations. Parallel objects connected to the substation should be split between the two bus sections; this ensures that the availability on, for example, the medium voltage side of parallel transformers is very high.

Conventional
With the conventional sectionalized single-busbar configuration, busbar disconnectors enable circuit breaker maintenance without deenergizing the busbar. Today the busbar adjacent disconnector requires more maintenance than the circuit breaker, hence busbar section availability is decreased compared to a disconnecting circuit breaker solution.

Disconnecting Circuit Breaker
The solution with disconnecting circuit breakers and a transfer busbar is not applicable. It is instead recommended to use a single busbar or sectionalized single busbar with disconnecting circuit breakers to improve substation availability.

Disconnecting Circuit Breaker
With the disconnecting circuit breaker solution, all disconnectors are removed; hence the maintenance interval for the substation is increased from approximately every five years to every fifteen years. Simplified interlocking configurations together with a smaller substation footprint and reduced maintenance requirements will provide cost benefits compared to the conventional solution. A sectionalized single bus with disconnecting circuit breakers provides better performance than a conventional double-busbar substation (in normal service they are connected in the same way), which has also been illustrated in the “Availability and reliability” section of the Application Guide.
Substation design
Double-busbar configurations

Double-busbar single breaker
In the double-busbar single-breaker configuration, the objects are typically split between the busbars, so that the substation is connected as a sectionalized single busbar under normal service conditions. When maintenance is required on one of the busbars or adjacent disconnectors, the other connected objects can be transferred to one busbar. In this case, only the object where maintenance is required is affected. A double busbar configuration also provides a certain flexibility in dedicating certain objects to a specific busbar in the substation.

Conventional
The double-busbar, single-breaker configuration was introduced to enable maintenance of busbar adjacent disconnectors without affecting the other connected objects in the substation. Maintenance of any of the equipment in the bay will take the connected object out of service.

Disconnecting Circuit Breaker
The disconnecting circuit breaker is not applicable in a double-busbar single-breaker solution because that configuration is based on disconnectors for switching between the busbars. If the double-busbar single-breaker solution is under consideration, it is recommended to use either a sectionalized single busbar with disconnecting circuit breaker (as they are connected in the same way, except when conventional disconnector maintenance is performed). If the substation reliability and availability is critical, a breaker-and-a-half or double-breaker configuration with disconnecting circuit breakers should be considered.

Double-busbar single breaker with transfer busbar
The double busbar with a transfer busbar works like a double-busbar solution and has the same advantages. In addition to the double-busbar configuration, the added transfer busbar (green) will also enable maintenance of the circuit breaker and its busbar disconnectors without affecting the connected object. Nonetheless, maintenance to the object adjacent and transfer disconnector will take the object out of service. In service, the double busbar with a transfer busbar will be connected as a sectionalized single busbar.

Conventional
This solution is commonly used in transmission substations and substations where high availability is a requirement. Operational procedures and maintenance requirements due to the increased amount of disconnectors are both complicated and time consuming.

Disconnecting Circuit Breaker
The disconnecting circuit breaker is not applicable in a double-busbar solution with a transfer busbar as that configuration is based on disconnectors for switching between the busbars. If the double-busbar solution with a transfer busbar is under consideration, ABB recommends the following possible solutions.

− Sectionalized single busbar with DCB (as they are connected in the same way, except when disconnector or circuit breaker maintenance is performed)

− If the substation has especially high availability and reliability requirements, a double-breaker or breaker-and-a-half solution with disconnecting circuit breakers is recommended.
Double-breaker configurations

Ring busbar
In a ring-busbar configuration, all objects are connected through two circuit breakers at the same time. Hence a single failure can affect a maximum of two objects in the substation. All connected objects share their two breakers with two other connected objects in the substation. It is recommended to alternate transformer and line connections so that a single failure does not risk affecting two transformers at the same time. Ring busbar configurations provide very good availability but are difficult to extend. A typical ring-busbar configuration contains a maximum of six objects.

Conventional
Maintenance of circuit breakers in this configuration does not affect the connected object. However, maintenance on the object adjacent disconnectors, which takes place approximately every three to six years, will require that the object be taken out of service.

Disconnecting Circuit Breaker
When disconnectors are removed, the ring-busbar substation footprint is decreased. Outages for connecting objects are decreased as the maintenance interval of the disconnecting circuit breakers is 15 years, instead of every three to six years as for conventional disconnectors.

Breaker-and-a-half arrangement
In the breaker-and-a-half configuration, each connected object is connected to one busbar through a circuit breaker and shares one circuit breaker with another object that is also connected to a second busbar. A failure in a configuration like this can affect a maximum of two objects. Breaker-and-a-half configurations provide very good availability, but require long term planning for connection of extending lines. A diameter in a breaker-and-a-half configuration refers to all equipment and connecting objects between the two busbars in a bay in the substation.

Conventional
Maintenance of circuit breakers in this configuration does not affect the connected object. However, maintenance on the object adjacent disconnectors, which takes place approximately every three to six years, will require that the object be taken out of service.

Disconnecting Circuit Breaker
When disconnectors are removed the breaker-and-a-half substation switchyard requires only about 60% of the space of a conventional solution. Outages for connected objects are decreased as the maintenance interval of the disconnecting circuit breakers is 15 years, instead of every three to six years as for conventional disconnectors.
Double-breaker

In the double-breaker configuration, each object is connected through a separate breaker to each of the two busbars. Under normal service conditions, both breakers are closed. A single failure in a configuration like this can only affect one object. Extending a double-breaker configuration is considered easier than for a ring-busbar or breaker-and-a-half configuration, as the objects can be connected from either side of the busbars.

Conventional

Maintenance of circuit breakers in this configuration does not affect the incoming object. However, maintenance on the object adjacent disconnectors, which takes place approximately every three to six years, will require that the object be taken out of service.

Disconnecting Circuit Breaker

When disconnectors are removed, the disconnecting circuit breaker switchyard requires only about 60% of the space of the conventional switchyard. Outages for connecting objects are decreased as the maintenance interval of the disconnecting circuit breakers is 15 years, instead of every three to six years as for conventional disconnectors.
Refurbishment and extension

Substation refurbishment and extension
When refurbishing substations there are mainly two alternatives:

- Full refurbishment (bay by bay/full substation refurbishment)
- Refurbishment equipment-by-equipment

The disconnecting circuit breaker can provide several benefits in substation extension and refurbishment, both full and equipment-by-equipment.

Full substation refurbishment approach (recommended)
Although a full substation refurbishment costs more initially compared to equipment-by-equipment refurbishment, it also provides certain technological advantages. When the entire substation is refurbished at the same time, new upgraded technology with better reliability can be implemented in the substation. By performing a complete refurbishment, a number of technical and commercial advantages can be obtained, such as:

- Future work will be minimized since all equipment has similar vintage.
- Single-line configuration can be adapted to developments in high-voltage apparatus and to any changes to the importance of the substation in the network since it was originally built.
- Outage times can be kept to a minimum by using the existing equipment to keep the substation in service during refurbishment.

- Utility personnel can concentrate on a few larger projects because the refurbished substations will not require service for many years after refurbishment.

Equipment-by-equipment-approach (not recommended)
What is considered an advantage in a full substation refurbishment approach is the opposite in an equipment-by-equipment approach. In this approach, new technology can often not be implemented in the substation and the engine (substation configuration setup) will stay the same. The main advantage with an equipment-by-equipment refurbishment approach is a lower initial cost as equipment often is bought under frame agreements, etc. With regard to the long term, this approach to refurbishing substations can be questioned.

In the case of equipment by equipment replacement, the disconnecting circuit breaker can be a very suitable alternative to conventional disconnectors and circuit breakers.

Examples of substation refurbishment
In the following example, a double busbar with a transfer busbar was upgraded to a sectionalized single busbar with disconnecting circuit breakers. The old transfer busbar was used to construct the new sectionalized single busbar with disconnecting circuit breakers. This conversion resulted in a 70% space reduction and increased reliability and availability for the substation.
Substation design
Refurbishment and extension

Before refurbishment of substation

After refurbishment of substation
Refurbishment and extension

The following section presents single-line diagrams that show how a substation extension or equipment replacement can be configured.

Double busbar extension example
In the case extension of an existing double busbar — either a sectionalized single busbar or double breaker solution with disconnecting circuit breakers would be suitable options, see the single-line diagram information earlier in this chapter for more information.

Example of extension of transfer busbar
As discussed earlier in this chapter, even a transfer busbar system can be easily extended or replaced by a single or sectionalized single busbar with a disconnecting circuit breakers. The simplified solution with disconnecting circuit breakers will enhance the reliability and availability of the substation, which can be verified with availability calculations.

Extension of traditional double busbar system

Extension of transfer bus system
Single busbar is the least complicated configuration and is preferably used in smaller substations with single line feed and lower voltages. Substation availability is increased compared to the conventional single busbar (also with a bypass disconnector or transfer busbar) solution due to elimination of maintenance-intensive disconnectors.

**Technical data**

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Single busbar configurations for the higher voltages are primarily recommended for use in "tap-on" substations. An example could be an added generation source to the transmission grid.

**Technical data**

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<tr>
<td>Substation system</td>
<td>Single busbar</td>
</tr>
<tr>
<td>Equipment</td>
<td>2 lines and 2 transformers</td>
</tr>
</tbody>
</table>
An H-configuration or sectionalized single bus is mainly used for smaller distribution substations. With two or more incoming lines and transformers, the availability of the medium voltage busbar is very high.

For distribution substations, a sectionalized single bus with disconnecting circuit breakers provides better performance than a conventional double busbar substation, which has also been illustrated in the availability section of the application guide.

### Technical data

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>System voltage</td>
<td>145 kV</td>
</tr>
<tr>
<td>Substation system</td>
<td>Sectionalized single busbar</td>
</tr>
<tr>
<td>Equipment</td>
<td>2 lines and 2 transformers</td>
</tr>
</tbody>
</table>
Sectionalized single busbar 420 kV

The DCB sectionalized single-busbar solution is often well suited for higher voltages, but this is dependent on the redundancy requirements of the substation. The DCB sectionalized single-busbar configuration is very good for transmission grids when there are space and financial constraints.

**Technical data**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
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<tbody>
<tr>
<td>System voltage</td>
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A breaker-and-a-half configuration is often used for larger transmission and primary distribution substations. In substations with less than three diameters, it is recommended to alternate the transformer connections between the different ends of the diameters to increase substation reliability. Availability and reliability are high as each object is normally fed from two directions.

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<table>
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<tr>
<th>Feature</th>
<th>Details</th>
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</thead>
<tbody>
<tr>
<td>System voltage</td>
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</tr>
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</tbody>
</table>
Double-breaker configurations provide the best performance regarding availability, reliability and service conditions. As all objects stay connected to both busbars at the same time through circuit breakers, there is no need for a bus coupler. If a failure occurs on a line or busbar, a maximum of one object will be affected.

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<table>
<thead>
<tr>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>System voltage</td>
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<tr>
<td>Substation system</td>
<td>Double breaker</td>
</tr>
<tr>
<td>Equipment</td>
<td>4 lines and 2 transformers</td>
</tr>
</tbody>
</table>
Double breaker 420 kV

Double-breaker configurations provide the best performance regarding availability, reliability and service conditions. The double-breaker solution is thus very popular in transmission grids with high requirements on the above mentioned parameters. The double breaker configuration is also very easy to extend.

**Technical data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>System voltage</td>
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<tr>
<td>Equipment</td>
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</tbody>
</table>
Layout examples
Ring bus 145 kV

Ring bus is suitable for smaller substations with up to six objects. Availability performance is very good as each object can be fed from two directions. The disadvantage contra sectionalized single bus is that the substation setup is more complicated to extend, which also affects the overview of the substation.

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</tbody>
</table>
Layout examples
Combination 145 kV

The combination setup provides the best of two worlds, with an economical setup combined with a high performance setup. Depending on the system requirements, the transformers can be connected with a double-breaker setup while the lines connect alternating to the two busbars.

Technical data

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<tbody>
<tr>
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<tr>
<td>Equipment</td>
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</tr>
</tbody>
</table>

Transformer bay with double breakers

Line bay with a single breaker
Double breaker 145 kV, extra compact configuration

Double-breaker configurations provide the best performance regarding availability, reliability and service conditions. As all objects stay connected to both busbars at the same time through circuit breakers, there is no need for a bus coupler. If a failure occurs on a line or busbar, a maximum of one object will be affected. The disconnecting circuit breaker can be placed directly under the busbar to create an extra compact solution.

**Technical data**

- System voltage: 145 kV
- Substation system: Double breaker
- Equipment: 4 lines and 2 transformers
The disconnecting circuit breaker enables high voltage, indoor AIS substations to be built. With an indoor ring bus configuration, availability and reliability are maximized while the cost of the substation is significantly lower compared to a GIS substation.

**Technical data**

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>System voltage</td>
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<td>Equipment</td>
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</tbody>
</table>
Single-busbar indoor substations have very high reliability as they are in a protected environment. The required space is optimized so that the substation footprint can be directly compared to a GIS substation, but at a lower cost.

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</tr>
</tbody>
</table>
Maintenance operation procedure

Double breaker example

NOTE: The following examples should be seen as a simplified explanation describing the process of removing a disconnecting circuit breaker from service while minimizing the outage consequence. The example may not be seen as an instruction for how this work is to be performed. National and local safety directives must be followed by trained personnel in all work in substations. ABB accepts no responsibility whatsoever for any damage to property or injury to personnel.

Scope of works
Isolate disconnecting circuit breaker for maintenance in order to be able to re-energize the line and busbar to minimize the outage time.

Part 1: Isolate disconnecting circuit breaker for maintenance by removal of conductors

1. SC opens relevant disconnecting circuit breakers
2. SC locks relevant disconnecting circuit breakers
3. SC closes relevant earthing switches
4. Maintenance personnel (SS - A) and (SS - B) enter the substation to apply padlocks on relevant disconnecting circuit breakers and earthing switches.
5. Maintenance personnel (SS - A) and (SS - B) performs zero voltage check and can set up maintenance earthing (portable earthing)
6. Maintenance personnel (SS - A) can open clamps to remove/loosen conductors

The disconnecting circuit breaker is now isolated with section clearance for maintenance, while the line and busbar can be returned to service to minimize the outage time.

Part 2: Re-energize line and busbar to minimize outage time

7. Maintenance personnel (SS - A) and (SS - B) enter the substation to remove padlocks on relevant disconnecting circuit breakers and earthing switches.
8. SC opens relevant earthing switches
9. SC unlocks relevant disconnecting circuit breakers
10. SC closes relevant disconnecting circuit breakers

The line and second busbar is now back in service to minimize outage time.

Operation sequence in Single Line Diagram (SLD)
Scope of works
Isolate disconnecting circuit breaker for maintenance to be able to re-energize the busbar to minimize busbar outage.

Part 1: Isolate disconnecting circuit breaker for maintenance by removal of conductors
1. SC opens relevant disconnecting circuit breakers
2. SC locks relevant disconnecting circuit breakers
3. SC closes relevant earthing switches
4. Maintenance personnel (SS - A) and (SS - B) enter the substation to apply padlocks on relevant disconnecting circuit breakers and earthing switches.
5. Maintenance personnel (SS - A) and (SS - B) performs zero voltage check and can set up maintenance earthing (portable earthing)
6. Maintenance personnel (SS - A) can open clamps to remove/loosen conductors

The disconnecting circuit breaker is now isolated with section clearance for maintenance, while the busbar can be returned to service to minimize outage time.

Part 2: Re-energize busbar to minimize outage time
7. Maintenance personnel (SS - A) enter the substation to remove padlocks on relevant disconnecting circuit breakers and earthing switches.
8. SC opens relevant earthing switches
9. SC unlocks relevant disconnecting circuit breakers
10. SC closes relevant disconnecting circuit breakers

The busbar is now back in service to minimize outage time.

Operation sequence in Single Line Diagram (SLD)
Functional specification
Creating a functional specification

A complete switchgear specification includes among other things, specification of the primary electric apparatus and systems.
Optimization of overall costs is a necessary measure in the deregulated energy market. The optimization of substations and their development is an objective continuously pursued by ABB. The focus is on functional requirements, reliability and cost over the total life cycle.

Specification
The single line diagram (SLD) is the basis for the specification, which can be a complete apparatus specification or a functional specification.
An apparatus specification has the advantage that the engineer specifies exactly what he/she wants, and will receive equivalent quotes from all bidders.
A functional specification enables the bidder to propose alternative ideas regarding apparatus and systems, and the bidder can sometimes quote more cost-effective solutions with better performance.
In any event, it is important that the inquiry allows the bidder to quote alternatives to that specified in the specification, without being disqualified.

Apparatus specification
The conventional way is to specify in detail all the equipment and the substation configuration/layout. All apparatus are specified with quantity and data. The layout, which often is based on a traditional approach, is also established. In this case, the asset owner receives equipment that is exactly what is wanted and what the asset owner is accustomed to buying. This way of specifying the equipment normally permits no alternatives to propose other solutions with better performance to lower the Life Cycle Cost.

To open the way for other solutions, a clause is sometimes included in the inquiry, stating that bidders are free to propose other equipment, for example in accordance to IEC 62271-108.

Functional specification
The main task for a substation is to transfer power in a controlled manner and to make it possible to make necessary switching/connections in the grid. Another way of specifying the equipment when planning a new plant or refurbishing an old substation can thus be to prepare a functional specification.

In this case, the bidder is free to propose the best solution, taking in account all the benefits that can be gained by using the best technology and the latest developed apparatus and systems, in combination with the requirements set for the substation and the network.

For example, basic requirements in a functional specification can be:

Number and type of system connections
– System electrical data
– Energy and transfer path through the system
– Unavailability related costs

Based on a functional specification, ABB can often propose an alternative solution, which provides better performance at considerably lower cost.

To back up decision-making, ABB can provide availability calculations, life cycle cost calculations, environmental impact reports, etc.

As the supplier takes a greater part of design responsibility, it is important that all related questions such as scope of supply, demands from authorities, special design conditions etc. are known at the beginning of the project.
Example of apparatus specification

Inquiry:
Please submit a quote for apparatus for 132 kV switchgear in five bays according to the specification and enclosed single-line diagram:

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>High voltage circuit breaker 145 kV, 3150 A, 31.5 kA</td>
</tr>
<tr>
<td>12</td>
<td>Motor operated disconnector 145 kV, 2000 A, 31.5 kA with integrated motor operated earthing switch</td>
</tr>
<tr>
<td>6</td>
<td>Current transformer 145 kV, 400/5/5/5/5 A. Core data...........................</td>
</tr>
<tr>
<td>9</td>
<td>Current transformer 145 kV, 2000/5/5/5/5 A. Core data...........................</td>
</tr>
<tr>
<td>12</td>
<td>Voltage transformer 145 kV, 132000/V3:110/V3:110/3 V. Core data...............</td>
</tr>
</tbody>
</table>
| 12| Surge arrester 132 kV...........................................................................

The suppliers will quote their best prices for the apparatus and the customer can pick apparatus with the lowest prices from different suppliers. The customer will thus have a cost-optimized set of apparatus.

Example of functional specification

Inquiry:
Please submit a quote for one 132 kV switchgear system with two incoming lines and two transformer feeders.

An existing line shall be cut and connected to the substation. Maximum energy transfer through the substation is 120 MVA. Power can flow in either direction. Maximum I_k 21 kA. Transformer data 132/11 kV, 40 MVA, U_k = 8%

Planned maintenance can be performed during low load periods but one of the transformers must always be in service.

In this case, ABB will quote a solution with disconnecting circuit breakers, which will provide an optimized total cost. The customer will have a quote for complete switchgear with a minimum of apparatus and high availability.

The single line diagram shows a solution with disconnecting circuit breakers.
www.dcbsubstations.com
Configurer votre propre disjoncteur de circuit en quatre étapes simples

www.dcbsubstations.com est un outil web où une solution conventionnelle peut être comparée à une solution de disjoncteur de circuit. Après avoir entré des informations de base telles que le niveau de tension, la configuration existante et le nombre de lignes et de transformateurs dans la sous-station, l’outil web vous donne trois options différentes :

- Solution recommandée par ABB — Basée sur vos entrées de niveau de tension, de configuration et de nombre de lignes et de transformateurs.
- Solution au minimum d’espace — Montrer la solution de disjoncteur de circuit qui nécessite l’espace le moins de place et est toujours une solution viable comparée au nombre de lignes et de transformateurs entrés.
- Solution de disponibilité maximale — Montrer la meilleure solution en termes de disponibilité et de fiabilité.

Le résultat donne un image 3D de la sous-station, un diagramme de ligne simple basique, un comparaison de coûts d’arrêt, une comparaison de disponibilité et une comparaison d’espace. Toutes les informations peuvent être envoyées par e-mail et si demandé, ABB peut vous contacter pour fournir des informations supplémentaires.

**Étape 1**
Select system voltage level

**Étape 2**
Select your configuration

**Étape 3**
Select number of lines and transformers
Step 4
View configuration

The result

Conventional 420 kV 1½ circuit breaker undefined vs 420 kV 1½ disconnecting circuit breaker

The 1½ DCB solution is a highly reliable and flexible solution that is often used in transmission applications and distribution substations. The solution is also very easy to extend.

<table>
<thead>
<tr>
<th>Object</th>
<th>Outage cost savings ($/year)</th>
<th>Outage time reduction (h/year)</th>
<th>Space reduction of switchyard (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Line</td>
<td>83100</td>
<td>4.62</td>
<td>32%</td>
</tr>
<tr>
<td>Single Transformer</td>
<td>83100</td>
<td>4.62</td>
<td></td>
</tr>
<tr>
<td>Parallel objects</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Image shows your DCB solution.
Click here to view high-res 3D image

Visit www.dcbsubstations.com