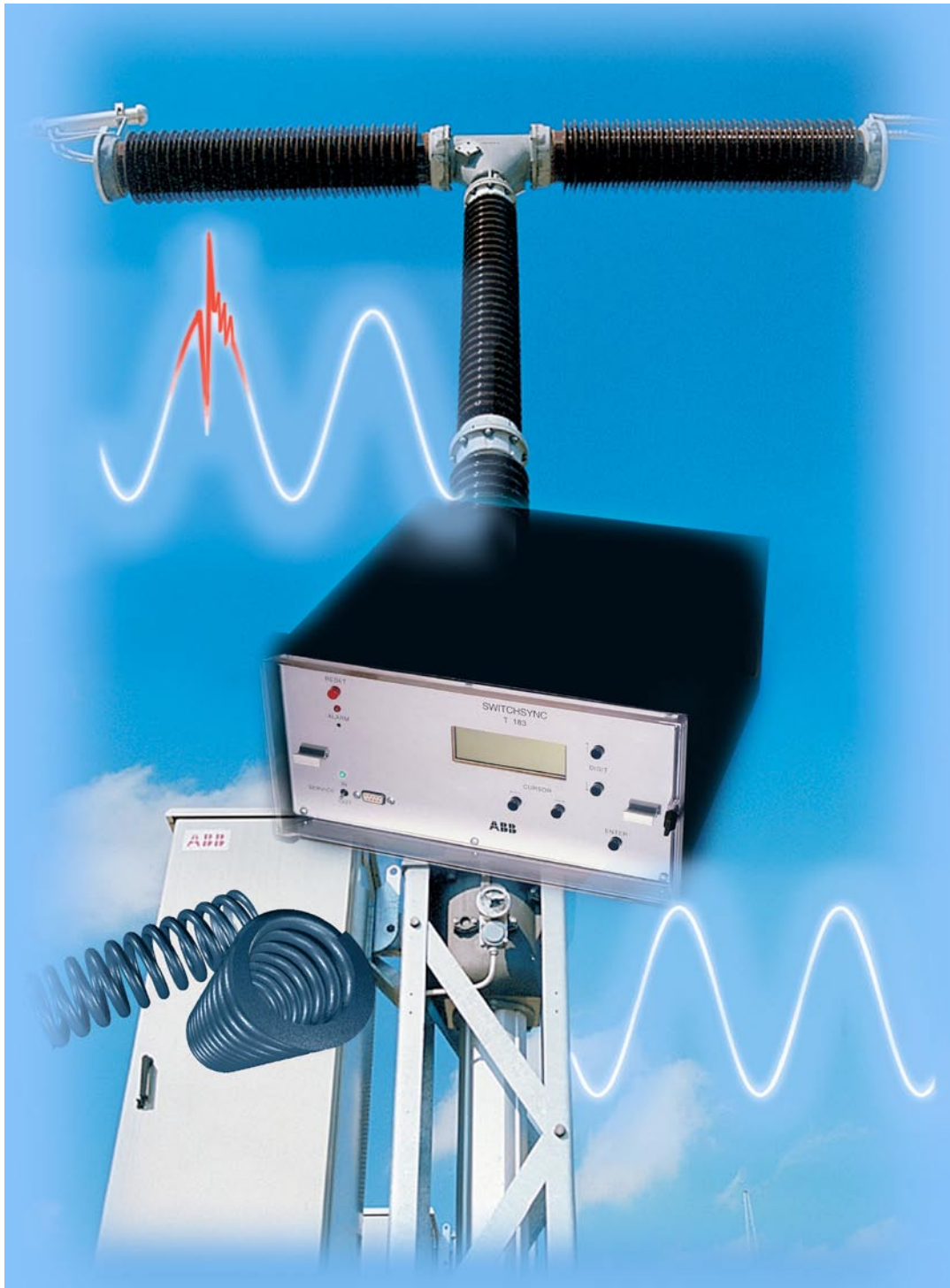


# Controlled Switching

Buyer's Guide  
Application Guide



Microprocessor based controllers for point-on-wave switching of ABB circuit breakers for transient reduction and improved power quality.



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# Controlled Switching with Switchsync™

ABB has extensive service experience with controlled switching, and the first generation of Switchsync™ controllers was launched in 1986. Controlled switching is used for elimination of harmful electrical transients upon planned switching of mainly capacitor banks, shunt reactors and power transformers. The method is also gaining acceptance for reenergizing of EHV transmission lines, and replacing traditional pre-insertion resistors. Since 1986, thousands of Switchsync™ controllers have been delivered all over the world.

ABB is at the forefront of development of controlled switching and its applications, and has built up unique expertise in switching transients and mitigation of related problems in both main and secondary circuits. Our development program is strongly focused on providing added value for our customers. A key aspect of all controlled switching applications is the precision achieved during making and breaking.

The live tank circuit breakers supplied by ABB are particularly well suited for controlled switching due to their good stability in regards to mechanical operating time and dynamic dielectric behavior. In addition, the Switchsync™ controllers are equipped with a special adaptive control, which compensates for any systematic variations in operating time. Necessary signals for the function are received from existing instrument transformers.

The Family of Switchsync™ controllers consists of:			
Switchsync™ Controller	Main Application	Controls Circuit Breaker Operation	Circuit Breaker Operation
E113	Shunt Capacitor Banks, Shunt Reactors	Open or Close	Three-pole
E213	Shunt Capacitor Banks	Open and Close	Three-pole
F236	Shunt Capacitor Banks, Shunt Reactors, Power Transformers	Open and Close	Single-pole
T183	Power Transformers	Close	Single-pole
L183	Uncompensated Transmission Lines	Close	Single-pole

All controllers have provisions for adaptive input to compensate for systematic variations in operating time of the circuit breaker. In addition, Switchsync™ F236, T183, and L183 have provisions for two external, predictive inputs (e.g. temperature variation, control voltage). These functions make it possible to achieve added precision in the timing of the controlled circuit breaker. They also have a data memory that stores information on switching times, thus permitting condition monitoring of the circuit breaker. Sensors for compensation purposes and communication software for all controllers except E-models are accessories that are ordered separately.



Switchsync™ E213 and F236



Circuit breaker HPL 550B2 controlled by Switchsync™ for smooth shunt reactor switching.

# Explanations

## Applications

<b>Applications</b>	<p>The following applications apply to controlled switching:</p> <p><u>Shunt capacitor banks:</u> Basic aim is to control closing to minimize the energizing transients (voltage transients as well as inrush currents). To improve interrupting performance, controlled opening can also be utilized.</p> <p><u>Shunt reactors:</u> Basic aim is to control de-energizing to ensure reignition-free behavior. In addition, controlled closing also serves as a useful method for minimizing inrush currents.</p> <p><u>No-load transformers:</u> The purpose of controlled no-load transformer switching is to minimize the inrush currents (and voltage distortion) by taking residual flux into account. Depending on the type of application and type of controller, controlled opening can serve as support for controlled closing.</p> <p><u>No-load overhead lines:</u> Controlled re-energizing or energizing of overhead lines ensures minimized switching transients.</p>
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## Load Characteristics

<b>Shunt Capacitor Banks</b>	<p>The shunt capacitor banks (or filter banks) may be grounded or ungrounded.</p> <p>Directly after de-energizing, the bank will be fully charged. Time relays normally block energizing of the capacitor banks until they are discharged.</p> <p>The shunt capacitor banks may be arranged either as a single bank or in a back-to-back configuration.</p>
<b>Shunt Reactors</b>	<p>The magnetic as well as electric circuit may vary. The following types of reactors may apply:</p> <ul style="list-style-type: none"> <li>- Shell type</li> <li>- Core type (single-phase units, five-limbed type or three-limbed type)</li> <li>- Air core type</li> </ul> <p>The electric circuit may be arranged in the following ways:</p> <ul style="list-style-type: none"> <li>- Y-connected and solidly grounded</li> <li>- Ungrounded (Y-connected or delta connected)</li> <li>- Reactor grounded</li> </ul> <p>Reactors are characterized by having a linear magnetizing characteristic curve (by air gap).</p>
<b>Power Transformers</b>	<p>Iron core as well as electrical connection of the windings may vary. Transformers are characterized by a non-linear magnetizing curve.</p>
<b>Uncompensated Transmission Lines</b>	<p>Line is characterized by having no compensation equipment between the line circuit breakers. With line CVT (Capacitor Voltage Transformer), a healthy phase will be fully charged for some seconds after de-energizing.</p>
<b>Shunt Reactor Compensated Transmission Lines</b>	<p>Line is characterized by having shunt reactors connected to the line and being switched together with the entire line.</p> <p>The voltage of a healthy line will oscillate for some seconds (depending on weather conditions and type of voltage transformers) with a frequency determined by the degree of compensation.</p>

## Load Characteristics cont.

<b>Series Compensated Transmission Lines</b>	<p>Line is characterized by having series capacitors forming a part of the line. Since the operating conditions may vary (bypassing series capacitor or not when interrupting healthy phases) the line voltage will be unpredictable.</p> <p>Combination with shunt reactor compensation may also apply.</p>
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## Strategies

<b>Shunt Capacitor Banks</b>	<p>Strategies are worked out for energizing all types of shunt capacitor banks and harmonic filter banks (grounded as well as ungrounded). The strategies involve energizing the load close to voltage zero across the circuit breaker contacts thereby avoiding energizing transients. The strategy assumes that the banks are discharged prior to energizing.</p> <p>For controlled opening, the strategy is to avoid short arcing times resulting in the highest risk for reignitions or restrikes. The need for controlled opening will depend on circuit breaker performance, load conditions and system frequency.</p> <p>For some applications it may be useful to de-energize a capacitor bank or filter bank such that it will be left at a certain voltage polarity. This is possible since the controller reference is a rectified signal making it possible to set the target with respect to the voltage polarity.</p>
<b>Shunt Reactors</b>	<p>All types of shunt reactors, independent of magnetic and electric circuit, can be switched in a controlled manner. The strategy for controlled opening is to select arcing times long enough to avoid reignitions at de-energizing.</p> <p>The strategy may vary depending on the size of the shunt reactor.</p> <p>The strategy for controlled closing is to energize at instants resulting in flux symmetry (current symmetry) thereby minimizing the risk for nuisance tripping and rotor vibrations in nearby generators due to zero sequence current.</p> <p>An alternative strategy for controlled energizing is to energize the reactor such that the voltage fronts will be minimized. This will require energizing close to voltage zero and there is no possibility to find compromise targets to reach both low inrush currents and low voltage fronts. It should also be noted that the zero sequence current protection needs to be disabled for a certain time or needs to be made less sensitive.</p>

# Explanations

## Strategies cont.

<b>Power Transformers</b>	<p>Common practice is to energize a power transformer from the side having the highest voltage. The strategy for controlled energizing of no-load transformers is to energize the load at instants resulting in flux symmetry by taking the residual flux into account. The residual flux may be high due to the non-linear magnetizing curve.</p> <p>The strategy also allows for energizing from the lower voltage side, which is less common.</p> <p>Three different strategies apply:</p> <ul style="list-style-type: none"> <li>- If the residual flux can be ignored, energizing instants at the voltage peak (zero flux) is selected. In cases such as these, the circuit breakers may either be single-pole or three-pole operated.</li> <li>- If the residual flux cannot be ignored controlled opening prior to controlled closing is a proper method that takes residual flux into account. Controlled opening then serves as support for the consecutive controlled closing operation. Controlled opening ensures repeatable flux conditions (polarity and magnitude). Making conditions are tuned to fit for the "locked" interrupting conditions. Circuit breakers switched using this strategy should preferably be single-pole operated.</li> <li>- Automatic targeting by residual flux measurement. This method requires that transformer type and load side voltage measurements are in accordance with the required combinations specified for controller T183. The circuit breaker must also be single-pole operated. The strategy in this case is to energize at instants when the prospective flux equals the residual flux. The flux is determined by the integration of the load side voltages.</li> </ul> <p>Besides that the main objective is to control the energizing by lowering the stresses at energizing of a transformer, it may also be useful to implement controlled de-energizing as the basic aim in some specific applications like switching arc furnace transformers. This is especially the case when vacuum circuit-breakers are used (which may for unfavorable arcing times cause repetitive re-ignitions) and can be done even if the circuit-breaker is three-pole operated and not modified by mechanical staggering. The controlled opening will avoid the risk for re-ignitions. Since the transformer is de-energized in loaded condition the phase shift between voltages and currents can vary which will require a current reference rather than a supply side voltage reference.</p>
<b>Uncompensated Transmission Lines</b>	<p>When switching off the healthy phases of a no-load uncompensated line, DC voltage will be trapped. This is the case unless magnetic VTs are used. For smooth re-energizing (or energizing), the line voltages are measured and energizing targets will be controlled to instants giving suitable and acceptable pre-strike voltages.</p> <p>Controller L183 requires a single-pole operated circuit breaker. The controller works for both single-phase line switching and three-phase line switching.</p> <p>A timing condition (&gt;20 s) changes the target to conditions for an uncharged line.</p>
<b>Shunt Reactor Compensated Transmission Lines</b>	<p>The optimum strategy is to re-energize the shunt reactor compensated line at instants when the difference voltage across the circuit breaker poles reaches beat minimum. However, this strategy would require a controller able to read the continuous voltage across the circuit breaker, which is not the case for L183.</p> <p>A simplified strategy targeting fixed contact touch instants independent of the line side voltage can be used. This method is preferably used in combination with line surge arresters.</p> <p>As an alternative solution a controller of type <b>CAT</b> can be used for controlled re-energizing of shunt reactor compensated lines.</p>

## Strategies cont.

<b>Series Compensated Transmission Lines</b>	No strategy exists for controlled reclosing of series compensated lines.
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## Switchsync™ Controllers

<b>Type of Controllers</b>	<p>The following five types of controllers are in the product program:</p> <p><b>E113</b>  <b>E213</b>  <b>F236</b>  <b>L183</b>  <b>T183</b></p> <p>The letters indicate basic function:  <b>E</b> = standard model for switching at fixed target(s)  <b>F</b> = fully equipped model for switching at fixed targets  <b>L</b> = special model for switching of uncompensated transmission lines  <b>T</b> = special model for switching of power transformers</p> <ul style="list-style-type: none"> <li>• First digit in name indicates the number of input commands.</li> <li>• Second digit indicates the number of adaptive channels or important signals for the function.</li> <li>• Third digit indicates the number of output commands.</li> </ul>
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## Features

<b>Frequency Adaptation</b>	<p>All Switchsync™ controllers are fully frequency adaptive.</p> <p>All Switchsync™ controllers are designed to work for system frequencies between 16 and 66 Hz except the model L183 for controlled no-load line switching, which is designed for frequencies between 45 and 66 Hz.</p>
<b>Input Check</b>	All controllers execute an input command check prior to processing an input command. An input check lasts about 40 ms.
<b>Operating Modes</b>	<p>All controllers except the L183 have the option of operating either in rapid or secure mode.</p> <p>In rapid mode (the operating mode for model L183), after the input check has been performed, the controller accepts the first found reference voltage zero.</p> <p>In secure mode, the controller will accept the fourth reference voltage zero after completion of the input check. Each cycle time of the last three cycles, prior to output activation, must agree with the continuously measured cycle time within specified tolerances. If not, a new count-down starts in order to find an accepted reference point. This will ensure more precise determination of the final reference prior to activation of the circuit breaker coil.</p>
<b>Adaptation</b>	<p>The result of a controlled closing operation can be supervised (and corrected accordingly in the next operation) by detection of voltage onset instant(s), current start instant(s) or current change instant(s) in the main circuit. Adaptation control will adjust the internally created waiting time when needed.</p> <p>For controlled opening (or closing), the contact separation instant can be supervised. The F236 model can also be programmed to supervise if current is flowing after the circuit breaker pole is supposed to have interrupted the current.</p>
<b>Remote Communication</b>	Modem remote communication with controllers F236, L183 and T183 can be arranged.
<b>Monitoring</b>	In adaptive mode, controllers F236, L183 and T183 store switching times, thus permitting the circuit breaker operating times to be monitored.



# Explanations

## Definitions

<b>Reference</b>	<p>For all Switchsync™ controllers, the reference is a busbar voltage transformer signal. Any phase-to-ground or phase-to-phase voltage can be used.</p> <p>A reference point is a reference voltage zero with positive derivative.</p> <p>Reference voltage frequency is continuously monitored and adaptation is automatically done for frequency variations.</p> <p>For special applications where the phase shift between voltage and current may not be constant, like when interrupting a loaded arc furnace transformer, it is possible to use a current / voltage converter and switch with reference to a current zero rather than a voltage zero. This will ensure a fixed contact separation target with respect to the wave shape of the current.</p>
<b>Targets</b>	<p>The targets for controlled switching may either be fixed or be determined by the interrupting conditions</p> <p>Controllers E113, E213 and F236 are used to switch the controlled circuit breaker at fixed switching instants (fixed making or contact touch instants and/or fixed arcing times at interruption).</p> <p>For controllers L183 and T183 the switching instants will vary. The targets will vary depending on the previous interrupting conditions and target for the next making operation is determined by load side voltage measurements.</p>
<b>Phase Shifts</b>	<p>All targets are expressed with respect to a reference time instant, that for all controllers is a busbar voltage zero or, in special applications, a current zero.</p> <p>For controlled closing, the target(s) are defined as a certain phase shift(s) with respect to the reference.</p> <p>For controlled opening, the ultimate targets are certain contact separation instants with respect to the phase shift of the load currents. Since the reference is a busbar voltage and the targets are to be expressed with respect to this it is assumed that there is a true phase shift of 90 electrical degrees (lagging or leading depending on inductive load or capacitive load) between the currents and phase-to-ground voltages.</p>
<b>Input Command</b>	Remote switching command given to the controller
<b>Waiting Time</b>	<p>The time between the final reference point and initiation of the output command is called waiting time.</p> <p>The waiting time (internally created by the controller) fills, together with circuit breaker operating time, the gap between the last detected reference point and the final target.</p>
<b>Output Command</b>	Delayed command from the controller to the circuit breaker. The command is processed in such a way that the activation of the closing and/or opening coil occurs at instants that will result in the intended optimum making instants and/or contact separation instants, assuming that make times and opening times are predictable.



## Instrument Transformers (Sensors)

<b>Voltage Transformers and Current Transformers</b>	The reference signal should be a permanent supply side voltage (busbar voltage). The reference voltage must be applied at least 300 ms prior to the given switching command.
<b>(VT's and CT's)</b>	<p>Any type of voltage transformer already existing in the system is suitable. Power consumption is less than 0.1 VA.</p> <p>When making instant and/or interrupting instant is monitored, a CT secondary signal is required. Any CT already existing in the system is suitable and no separate core is needed.</p> <p>For the L183 and T183 load side voltage measurements are needed for determination of the load conditions.</p>

## Transducers

<b>Compensation</b>	<p>When the circuit breaker has a well-known variation in its behavior, with variations in external conditions, corrections for these can be made.</p> <p>The controllers F236, L183 and T183 each have two compensation sensor inputs. An example of possible external conditions that can be compensated for are operating time variations due to ambient temperature changes and variations in auxiliary voltage for the circuit breaker coils.</p> <p>Any external parameter variation giving a known dependency can be compensated for by suitable sensors. The sensors are optional and are to be ordered separately.</p> <p>The compensation features are especially meaningful for circuit breakers that are not switched frequently.</p> <p>The signal from the transducer to the controller must be in the range 4 to 20 mA.</p> <p>For circuit breakers frequently operated, the external parameter change influencing circuit breaker behavior can be considered as minor and compensated for by adaptation control.</p> <p>Compensation equipment is mainly intended for circuit breakers that are not frequently operated.</p>
<b>Precision Auxiliary Contacts</b>	If the instants for the contact touch or contact separation are being monitored, ABB advises using special inductive auxiliary contacts (NAMCO type I 605.A2 ID No. 724988).

# Explanations

## Circuit Breaker Characteristics

<b>Single-pole or Three-pole Operation</b>	<p>When a single-pole operated circuit breaker is controlled, a separate output command is given to each pole.</p> <p>Three-pole operated circuit breakers can be arranged with mechanical staggering, making them suitable for controlled switching. In these cases, there will be a built-in mechanical spread (phase shift) between the poles that is appropriate for optimized switching of the load at the specified frequency. The mechanical spread is arranged to reach proper switching conditions with minimum staggering (which for grounded loads means switching in reversed phase rotation order).</p> <p>The suitability/need of controlled opening of a three-pole operated circuit breaker depends on the load conditions and the relationship between the closing and opening speeds. Note that time staggering for opening will be reversed in comparison to closing (which normally is the preferred).</p> <p>Note that it is not always possible to combine controlled closing and controlled opening with three-pole operated circuit breakers.</p> <p>For the control of a single-pole operated circuit-breaker individual switching commands are given to each pole respectively. In that case the non-simultaneity is achieved by electrical means and the staggering is named electrical staggering.</p>
<b>Interface controller-mechanism</b>	<p>All circuit breakers having operating coils are suitable for direct connection to the controller.</p> <p>For special operating mechanisms having no operating coils, like the Motor Drive™ additional resistors, simulating the coils must be installed in parallel with the output command circuits. Suitable resistors are for example ELFA 60-674-33.</p>
<b>Staggering</b>	<p>In controlled switching, the optimum targets for each circuit breaker pole do not coincide. When three-pole operated circuit breakers are used, a mechanical phase shift must be built in. This mechanical phase shift, staggering, ensures that contact touch and/or contact separation for all poles occur at intended instants. This mechanical staggering is achieved by special design of the mechanical linkages in the bottom mechanism housings.</p> <p>For a three-pole operated circuit breaker, only one pole, the master pole, is controlled while the other two operate in slave mode.</p> <p>For single-pole operated circuit breakers the staggering is electrically arranged by non-simultaneous individual switching commands.</p> <p><b>Note! All details about the load must be well known before offering a mechanically staggered circuit breaker.</b></p>
<b>RDDS</b>	<p>Rate of <u>D</u>ecrease of <u>D</u>ielectric <u>S</u>trength. Circuit breaker characteristic that describes the rate of fall of the voltage withstand at closing of a circuit breaker.</p> <p>For proper function, the value of RDDS should exceed the maximum derivative of the applied voltage. Statistical variation of RDDS should be low.</p>
<b>RRDS</b>	<p><u>R</u>ate of <u>R</u>ise of <u>D</u>ielectric <u>S</u>trength. Circuit breaker characteristic that describes the rate of rise of the voltage withstand at opening of a circuit breaker. The value of the RRDS defines the minimum arcing time needed for reignition-free interruption of inductive loads.</p>
<b>Closing Time</b>	<p>Time from energizing the closing coil until contact touch in the circuit breaker.</p>

## Circuit Breaker Characteristics cont.

<b>Make Time</b>	Time from energizing the closing coil until current starts to flow in the main circuit. Adaptation control adjusts the making instant.
<b>Pre-arcing Time</b>	Time from start of current flow in the main circuit until contact touch. Pre-arcing time = Closing time - Make time
<b>Restrike</b>	Voltage breakdown in the circuit breaker at a time equal to or exceeding a quarter of a cycle after attempt to interrupt.
<b>Reignition</b>	Voltage breakdown in the circuit breaker within a quarter of a cycle from attempt to interrupt.
<b>Opening Time</b>	Time from energizing the opening coil until contact separation occurs.
<b>Arcing Time</b>	Time from contact separation until current interruption.

## Control Circuit Arrangements

<b>Fault Clearance</b>	Since a controlled opening operation will cause an extended clearing time (input check duration, time for finding final reference point and additional waiting time) it is important to arrange all fault tripping commands to bypass the controller.
<b>Trip Circuit Supervision (TCS)</b> <b>Close Circuit Supervision (CCS)</b>	Trip or Close Circuit Supervision can be arranged but must be installed in the controller output circuit. No Close or Trip Circuit Supervision should be installed in the controller input circuit.

## System and Switching Conditions

<b>Grounding of the Load</b>	The type of grounding of the load is an important parameter for defining the optimum targets for controlled switching. The grounding of the load also defines the optimum mechanical staggering of the three-pole operated circuit breakers.
<b>Connection of Main Circuit</b>	A three-pole operated, mechanically staggered circuit breaker is not symmetrical. Therefore in some applications, for most grounded loads, it is very important that the recommended pole-phase connections are followed. The principle is that intended making or breaking operations shall take place in reverse phase order (i.e. order R-T-S in a network with positive sequence voltages in order R-S-T).  Information about relevant alternative connections is available at ABB Power Technologies, High Voltage Products, Ludvika, Sweden.
<b>Trapped Charge</b>	DC voltage left on a capacitor bank or uncompensated transmission line after interruption.
<b>Residual Flux</b>	Remaining flux in the transformer core after de-energizing.
<b>Phase designations</b>	In a three-phase system the three phases may be named differently depending on utility practices. Examples of some typical phase designations are: A-B-C, R-S-T, R-Y-B, L1-L2-L3 and 0-4-8. All three-phase examples in this document are shown using the phase designations R-S-T and with a phase rotation equal to R->S->T.

# Explanations

## Configuration of Substations

<b>Substations</b>	<p>Different substation arrangements may call for special solutions for overall total functionality. Double circuit breaker schemes and “one-and-a half” circuit breaker schemes (breaker-and-a-half) may require special arrangements for attaining proper function of adaptation control.</p> <p>For full flexibility, one-and-a half circuit breaker schemes require special design of control circuits and more than one controller per circuit breaker.</p>
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## Type and Routine Test

<b>Tests</b>	Type and routine tests are performed in accordance with international standards. See Quality Control and Testing, Chapter N-1.
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## Commissioning

<b>Commissioning</b>	<p>Upon commissioning, it is advisable to record some controlled switching operations to judge the overall performance of the complete controlled switching system.</p> <p>When controlled switching is arranged by using controllers E113, E213 and F236 our recommendation is to record the following quantities:</p> <ul style="list-style-type: none"><li>- Busbar voltages (or at least the reference voltage)</li><li>- Load currents</li><li>- Processed delayed output command(s)</li></ul> <p>The processed output commands are used to determine contact separation and permit for evaluation of the arcing times.</p> <p>The same quantities should be recorded when switching is controlled by controllers L183 and T183. If possible, it is also advisable to record the load side voltages when using these controllers.</p>
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Customer's  
Notes

# Introduction - Controlled Switching with Switchsync™

## Suppression of Switching Transients

There are several important circuit breaker applications where random closing or opening instants may lead to severe voltage and current switching transients. These transients occur in the main circuits, but may also induce transients in control and auxiliary circuits, as well as in adjacent low voltage systems. The switching transients are associated with a variety of dielectric and mechanical stresses on the high-voltage equipment, and may cause gradual or immediate damage to the system or the equipment. Induced transients may lead to a variety of disturbances, e.g. in substation control and protection systems, computers and processors, or telecommunications.

Normal energizing of shunt capacitors, shunt reactors and power transformers may cause severe transients - high overvoltages, under-voltages, or high inrush currents. Upon de-energizing of shunt reactors, reignitions will occur, resulting in steep voltage surges. The magnitude of the transients depends on the point-on-wave where closing or opening of the circuit breaker contacts occur. In a situation without controlled switching, sooner or later the switching instant will occur at the worst possible phase angle.

Even though a modern circuit breaker will have very low restrike probability at switching of capacitive loads or harmonic filters, for statistical reasons a few occasional restrikes may occur during the course of a large number of switching operations. This risk of occasional restrikes may be eliminated by means of controlled opening operations.

Conventional countermeasures such as pre-insertion resistors, damping reactors or resistors, or arresters are used to limit the magnitude and effect of the switching transients, after they have occurred. In addition, system and equipment insulation may be upgraded to withstand the stresses. These methods, however, may be inefficient, unreliable or expensive, and do not treat the root of the problem.

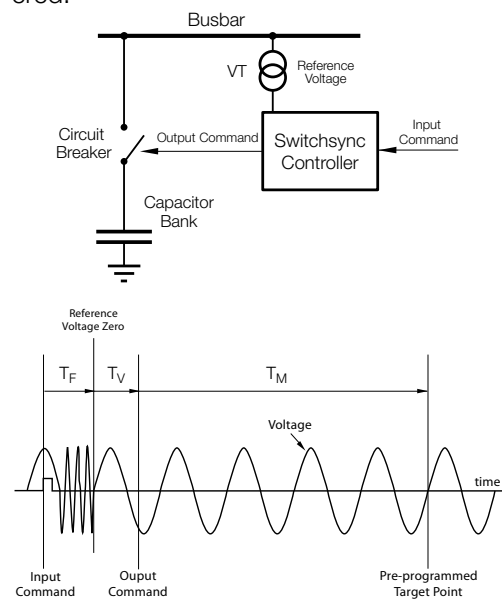
## Principle of Controlled Switching

Controlled switching is a method for eliminating harmful transients via time controlled switching operations. Closing or opening commands to the circuit breaker are delayed in such a way that making or contact separation will occur at the optimum time instant related to the phase angle.



By means of Switchsync™ controllers, both energizing and de-energizing operations can be controlled with regard to the point-on-wave position, and no harmful transients will be generated.

The following example illustrates the general operating principle of a Switchsync™ controller, for energizing of a capacitor bank. In order to avoid switching transients, the making instant in this case shall be at voltage zero. For simplicity, only a single phase is considered.



$T_F$  = Time to detect final reference voltage zero  
 $T_V$  = Waiting time  
 $T_M$  = Expected make time of circuit breaker

If controlled opening is applied it is important that all protection trip commands, in the event of fault interruptions, are by-passing the controller. In secure mode operation the "controlled way" is typically extended by about 120 ms at 50 Hz compared to a direct trip command.

When the capacitor bank is to be energized, an input command is given to the Switch-sync™ controller. Following the command, the controller will determine a reference time instant, related to the phase angle of the busbar voltage. When this has been done, and after an internally created waiting time, the controller will then give an output closing command to the circuit breaker. The time instant for the output closing command is determined by the make time of the circuit breaker and the target point for making. Both the predictable make time and target point have been pre-programmed into the controller. The circuit breaker will then make the current at the correct time instant and minimize the switching transients.

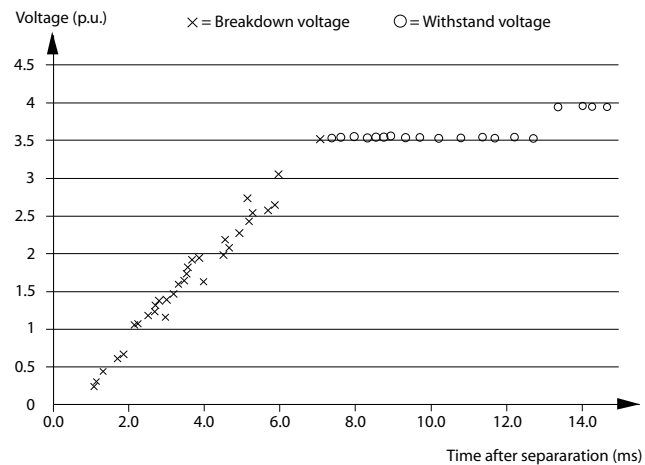
### Suitable Circuit Breakers

ABB live tank circuit breakers and disconnecting circuit breakers have spring operating mechanisms. For some of the variants, a motor drive is incorporated as an alternative. All these circuit breakers have stable operating times, which vary only to a limited extent with factors such as ambient temperature and control voltage. For moderate variation of these factors, the opening and closing times will typically show a variation of less than plus/minus 0.5 ms. Similarly, after a long idle time, either in closed or open position, the circuit breakers will have stable operating times, even upon the first operation.

The circuit breakers also have high and stable dynamic dielectric withstand capability between the contacts, both upon making and breaking operations. These properties, together with the stable operating times, make these circuit breakers well suited for controlled switching.

A typical example of measured RRDS (Rate of Rise of Dielectric Strength) of a circuit breaker is shown in figure below where x points represent voltage breakdowns at a certain time after contact separation and

where rings indicate tests resulting in voltage withstand:



The RRDS determination is done at no-load opening operations by determining the flashover limit at different contact distances (times after contact separation) by applying a rapidly increasing voltage at pre-determined distances/times.

The no-load determined RRDS shall be compared to results from shunt reactor interruption tests to also verify that the arcing gives no further reduction to the measured RRDS. Based on experiences there is almost no impact on the withstand performance compared to the cold characteristics if the interrupting current is in the range of some hundreds of amps.

Since stable dynamic dielectric properties, also having a high rate of change, are required for attaining successful performance for controlled switching, it is not advisable to combine pre-insertion resistors and controlled closing.

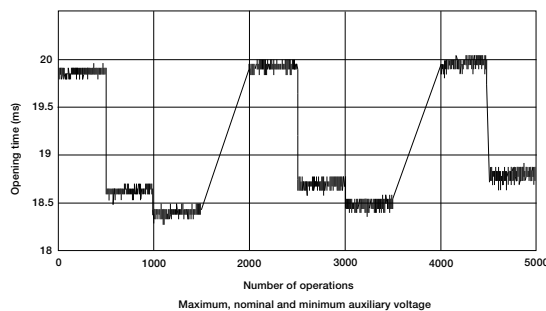
The dynamic dielectric properties of the pre-insertion resistor contacts are not steep enough or stable enough to be suitable for controlled closing. In adaptive operating mode, this condition may lead to unstable adaptation control.



# Introduction - Controlled Switching with Switchsync™

It should be noted that circuit breakers of other design, e.g. using other types of mechanisms, may show larger variations in operating times, statistically from operation to operation, and also as a result of variations in ambient temperature etc. It may therefore be less beneficial to use such circuit breakers for controlled switching applications. The dielectric properties between the contacts, upon making or breaking operations, may also be less suitable.

For good results, and appropriate limitation of the switching transients, we recommend use of Switchsync™ controllers only with ABB's SF<sub>6</sub> live tank circuit breakers.



**Example of opening time measurements from a mechanical endurance test.**  
**Test result shown for the extreme conditions where the control voltage varies between 70 and 110%.**

## Switchsync™ for Condition Monitoring

The Switchsync™ controllers F236, L183 and T183 have integrated data memories that store information on make times for a large number of operations. This information may be used for condition monitoring of the controlled circuit breaker.

## Experience

ABB has nearly 20 years of service experience with controlled switching, and the first generation of Switchsync™ controllers was launched in 1986. ABB is at the forefront of development in this area and has built up unique expertise in switching transients and mitigation of related problems in both main and secondary circuits, as well as EMC aspects.

Presently, thousands of Switchsync™ controllers are in operation. More than half of the applications are for capacitor banks and harmonic filters, about 25% for shunt reactors and about 15% for power transformers.

## Testing and standards

IEC is at the moment defining test requirements for circuit-breakers intended for controlled switching applications. The outcome of the IEC work will be published in Technical report IEC 62271-302.

Customer's  
Notes

# Switching of Capacitor Banks and Harmonic Filters

## Control of Closing Operations

Switchsync™ circuit breaker controllers for shunt capacitor banks and harmonic filters are normally used for control of closing operations.

When a capacitor bank or harmonic filter bank is de-energized, it takes a certain time for residual charge to disappear. In order to avoid energizing a capacitor bank while still charged, a time relay is normally applied for blocking of the circuit-breaker mechanism. Build-in discharge resistors will make sure that the bank is discharged when the interlocking has expired.

A typical relay setting is 10 minutes from opening of the circuit-breaker to the earliest possible subsequent closing operation.

A discharged capacitor is similar to a momentary short-circuit when connected to a power source. If energized when the source voltage is high, the connection results in voltage and current transients that may cause serious problems. Depending on the network configuration, the voltage surge may cause dielectric breakdown somewhere in the high voltage network, and low voltage equipment may suffer insulation damage or malfunction. With back-to-back capacitor banks, the inrush current may have high frequency and high amplitude. In extreme cases, it may threaten the mechanical integrity of both the capacitor bank and circuit breaker. Controlling the circuit breaker to energize a capacitive load at zero voltage across the contacts will eliminate harmful transients.

Upon a closing operation, the contacts in a circuit breaker pole will have a dielectric withstand capability that rapidly decreases from a high starting value towards zero, when the contacts touch. This property is often referred to as RDDS, Rate of Decrease of Dielectric Strength, of the circuit breaker.

In an ideal case, the circuit breaker contacts should touch exactly when the voltage across the contacts is zero. For this to be possible, the RDDS of the circuit breaker Upon a closing operation, the contacts in a circuit breaker pole will have a dielectric withstand capability that rapidly decreases from a high starting value towards zero, when the contacts touch. This property is often referred to as RDDS, Rate of Decrease of Dielectric Strength, of the circuit breaker.

In an ideal case, the circuit breaker contacts should touch exactly when the voltage across the contacts is zero. For this to be possible, the RDDS of the circuit breaker needs to be higher than the rate-of-fall of the applied voltage close to zero. In reality there will always be a certain scatter in closing speed and dielectric withstand characteristics of the contacts. In order to minimize the adverse effect of such statistical variations and due to the limited speed, the nominal making target is therefore set slightly after voltage zero, as illustrated in Figure 1.

Figure 2 shows by means of an example how efficiently controlled switching eliminates the harmful switching transients related to energizing of a capacitor bank.

Even in a very unlikely case with the most unfavorable statistical scatter of closing time and dielectric withstand characteristics; the switching transient would be decreased to less than 30 % of what may occur in an uncontrolled situation.

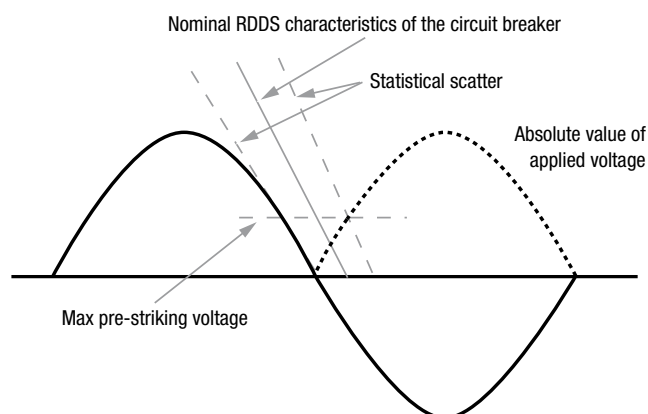


Figure 1. Energizing at voltage zero. The nominal making target is set slightly after voltage zero in order to minimize influence of statistical variations.

# Switching of Capacitor Banks and Harmonic Filters

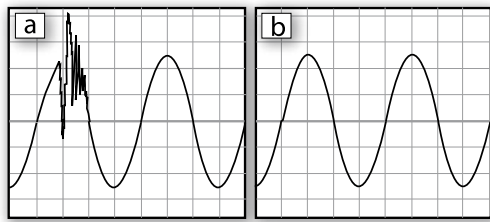


Figure 2.

Voltage transients when energizing one phase of a 72 kV capacitor bank

- At an unsuitable point-on-wave position, close to the power frequency voltage peak, a high voltage transient is generated.
- With Switchsync™ controller, energizing occurs close to voltage zero, and no transient is generated.



One phase of 300 kV, 200 Mvar capacitor bank, Norway

## Damping Reactors

Traditionally, damping reactors are often used for single and back-to-back shunt capacitor banks. Because these reactors are intended to limit inrush currents, they are normally superfluous when controlled closing is utilized. The capacitor bank, circuit breaker, and system will normally be able to handle the stresses if an uncontrolled making operation for some reason should occur.

Sometimes, however, damping reactors are utilized in order to limit high frequency transients created by interaction of the capacitor bank with other parts of the network in connection with faults outside that bay. In this case, the capacitor bank circuit breaker is not involved, and damping reactors are still required when controlled switching of the circuit breaker is used.

## Three-phase Conditions

For controlled capacitor bank energizing, the three circuit breaker poles should close at different time instants. The time differences depend on the application.

For capacitor banks with grounded neutral, the three poles should close in succession with a time separation of 1/6 cycle (3.3 ms at 50 Hz or 2.8 ms at 60 Hz).

For capacitor banks with ungrounded neutral, two poles should close simultaneously at phase - phase voltage zero, and the last one 1/4 cycle later (5 ms at 50 Hz or 4.2 ms at 60 Hz). See Figure 3.

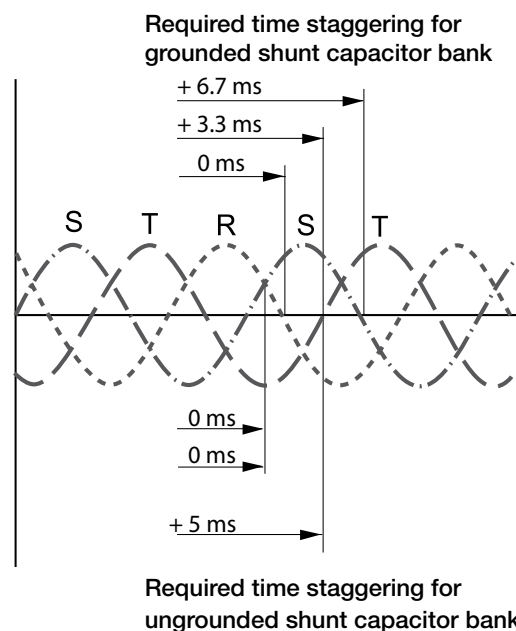


Figure 3.

Example of making sequences versus the phase-to-ground busbar voltages for a 50 Hz capacitor bank. The minor time deviations from voltage zero across contacts, discussed in Figure 1, have been disregarded.

# Switching of Capacitor Banks and Harmonic Filters

## Staggering of Circuit Breakers

In case of a single-pole operated circuit breaker, Switchsync™ will control each pole individually to make it close at the right time. For a three-pole operated circuit breaker, with only one operating mechanism, the poles are mechanically adjusted (staggered) in order to close at the right instant. For switching of a shunt capacitor bank or harmonic filter, the actual choice of staggering depends on:

- Connection of the neutral of the load - grounded or ungrounded
- System frequency - 50 or 60 Hz

Staggering may also be arranged for other applications, such as de-energizing of shunt reactors.

*Note:*

*Mechanical staggering of a circuit breaker will affect both closing and opening times of the individual poles. When staggering has been chosen for control of closing operations, opening operations will also be influenced. The influence is small, however, and can normally be disregarded.*

*There is one exception:*

*Staggered LTB 170D1/BUS circuit breakers utilized for controlled closing of ungrounded 170 kV capacitor banks, also require Switchsync™ control of opening operations, in order to retain very low risk for restrikes.*

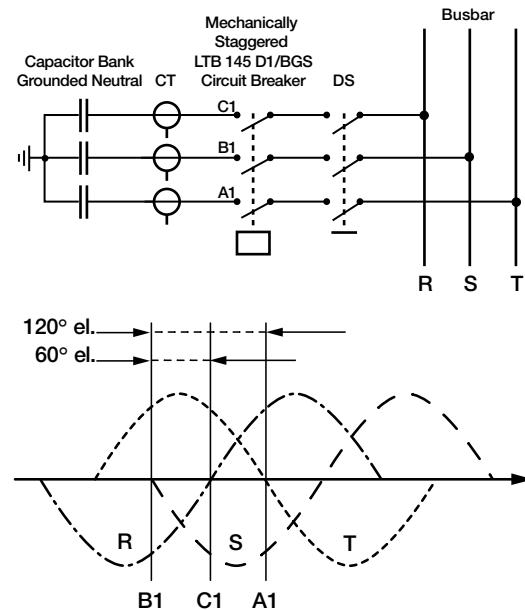
## Connection of Staggered Circuit Breakers




It is important to observe that for correct function, staggered circuit breakers intended for *grounded* capacitor banks must be properly connected on site.

Correct connection depends on the circuit breaker type and is illustrated in Figures 4 and 5 for the LTB 145D1/BGS. With a positive phase sequence R-S-T of the supply network, the phase-pole connections in this case shall be:

Busbar Voltage	Circuit Breaker Pole	Staggering of Closing Instant, El. Degrees
R	C1	+60°
S	B1	0°
T	A1	+120°



**Figure 4 and 5.**  
Connection of staggered LTB 145D1/BGS circuit breaker for shunt capacitor bank with grounded neutral.

If the recommended pole-phase connections are not observed, it is impossible for all three poles to close adjacent to their respective voltage zeroes, and severe switching transients will be generated. 

For staggered circuit breakers intended for ungrounded capacitor banks, there is no similar limitation to the phase-pole connections.

For permissible connections of staggered circuit breakers, see the separate appendix. Please contact ABB Power Technologies, High Voltage Products, Ludvika, Sweden.

## Control of Opening Operations

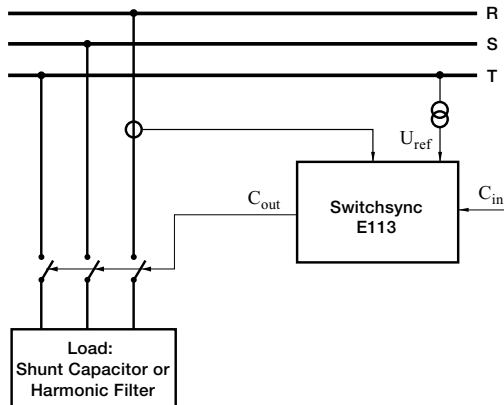
Opening of capacitor bank circuit breakers generally does not lead to any significant switching transients. The major reason is that the circuit breakers are designed to have very low risk of restrikes upon interruption of capacitive current. However, in special cases with severe conditions, the Switchsync™ may be utilized in controlled opening of capacitor bank circuit breakers. The aim is then to eliminate the small statistical risk that a re-strike may still occur, and the circuit breaker is controlled in such a manner that short arcing times are avoided.

# Switching of Capacitor Banks and Harmonic Filters

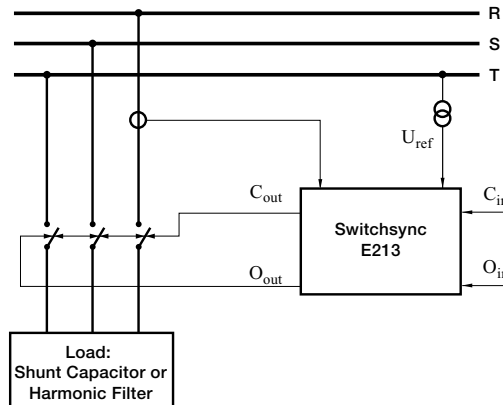
## Suitable Switchsync™ Controllers

### Three-pole Operated and Mechanically Staggered Circuit Breakers

Only closing: Switchsync™ E113



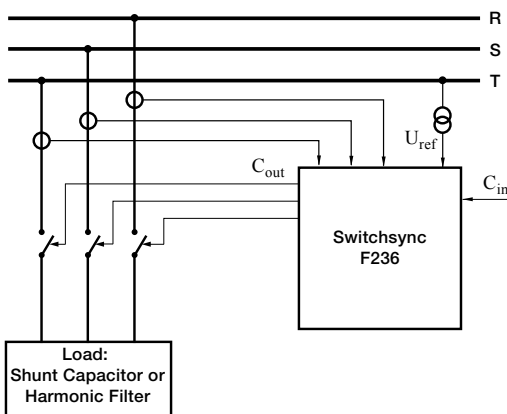
Both closing and opening: Switchsync™ E213



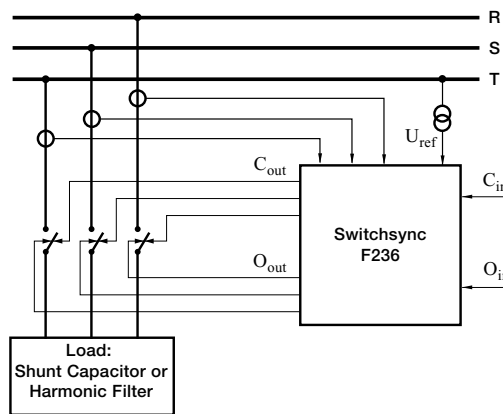
Suitable conditions for combined controlled opening and controlled closing exist for ungrounded capacitor banks. The need for controlled opening of grounded capacitor banks is low.

### Single-pole Operated Circuit Breakers

Only closing: Switchsync™ F236



Both closing and opening: Switchsync™ F236



#### Legend:

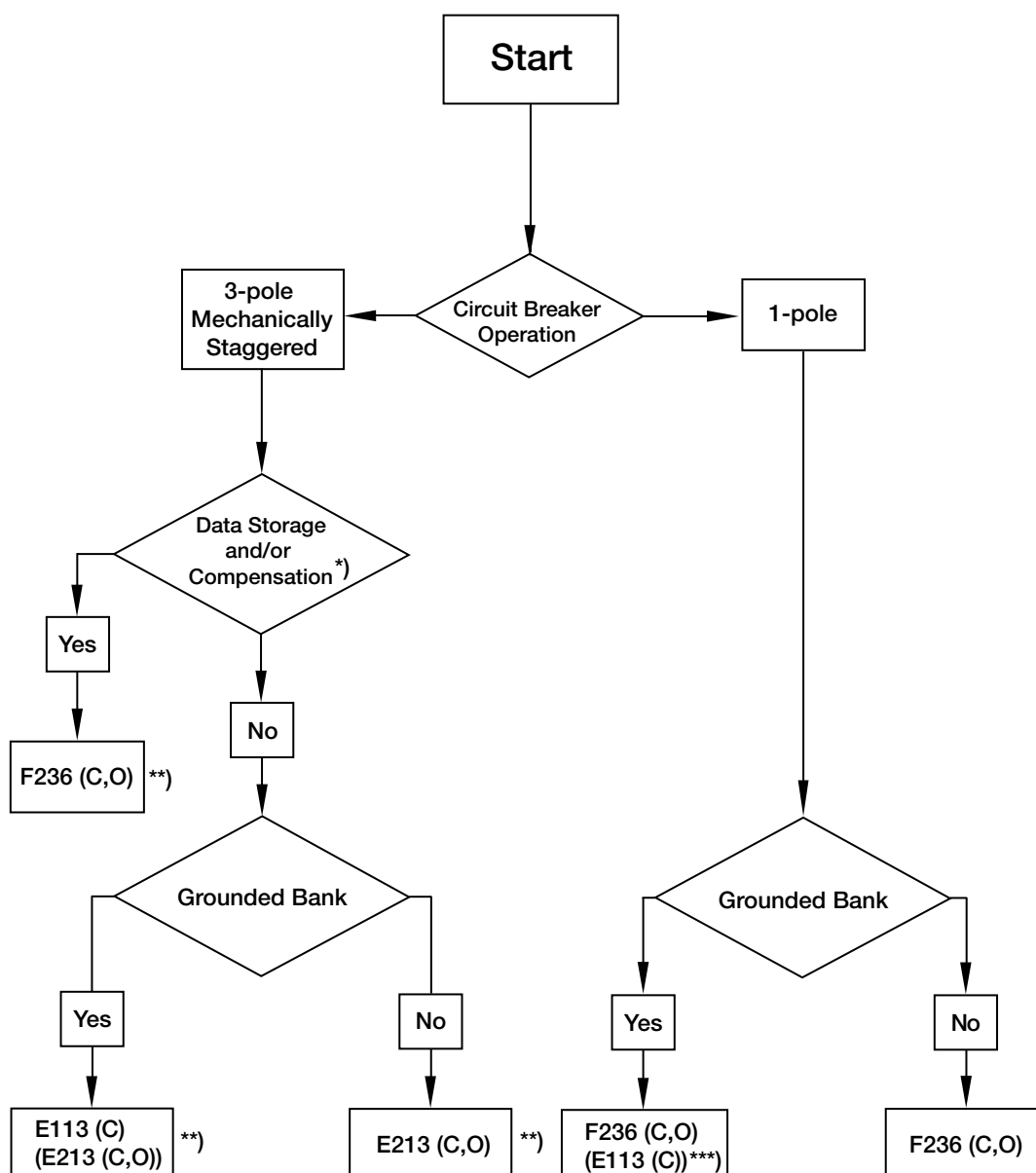
R,S,T	Three-phase busbar
$C_{in}$	Closing command input
$O_{in}$	Opening command input
$U_{ref}$	Reference voltage input
$C_{out}$	Closing command output
$O_{out}$	Opening command output

The purpose of the CT secondary feedback signal is for adaptation control.

All examples are shown with reference in phase T. However, any voltage with a known phase shift can be used as a reference.

# Switchsync™ Selection-tree

## Switching of Capacitor Banks and Harmonic Filters



\*) Compensation for control voltage, temperature etc.

\*\*) Check that correct circuit breaker solution exists

\*\*\*) No individual adaptation control



## Switching of Capacitor Banks and Harmonic Filters

Customer's  
Notes

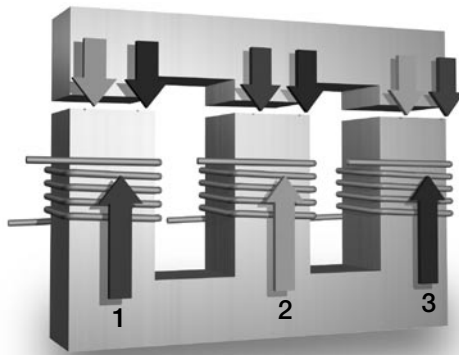
# Switching of Shunt Reactors

## Shunt Reactor Design and Operation

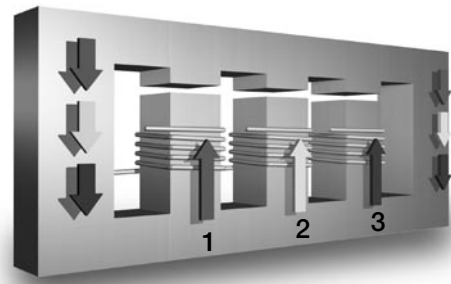
Shunt reactors are mainly used in transmission networks. Their function is to consume the excess reactive power generated by overhead lines under low-load conditions, and thereby stabilize the system voltage. They are quite often switched in and out on a daily basis, following the load situation in the system. Shunt reactors are normally connected to substation busbars, but also quite often directly to overhead lines. Alternatively, they may also be connected to tertiary windings of power transformers. The reactors may have grounded, ungrounded, or reactor grounded neutral.

Shunt reactors normally have iron cores with integrated air gaps. Due to the air gaps, the iron cores cannot be significantly saturated, and the reactors therefore will have a reasonably linear behavior during energizing events, for example.

Three-phase shunt reactors may consist of three separate single-phase units, or be complete three-phase units with common core and tank. Common, three-phase cores may be of either five-leg (alternatively shell type) or three-leg design, see Figures 1a and 1b. Five-leg cores and shell type cores are mainly used for transmission voltages. They make the three phases magnetically independent, while three-leg cores lead to magnetic coupling between the phases. The type of core - together with the winding arrangement (Y- or D-connection) and grounding conditions - therefore influences the switching sequences utilized for controlled switching.



**Figure 1a.**  
Three-leg (limbed) shunt reactor core



**Figure 1b.**  
Five-leg (limbed) shunt reactor core with three wound limbs

1= Magnetic flux phase R  
2= Magnetic flux phase S  
3= Magnetic flux phase T

Medium voltage reactors, connected to tertiary windings of transformers, in most cases have air-insulated windings without iron cores.

## Use of Neutral Reactors

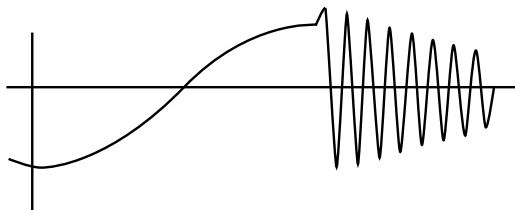
For line connected shunt reactors, an additional single-phase reactor (neutral reactor) is sometimes connected between neutral and ground. The purpose of this reactor is to increase the overall zero sequence reactance of the overhead line. In this way, the fault current is kept small in the event of single-phase line faults cleared by single-pole opening of the line breakers. As a result, there will be a high probability that the arc at the fault location is extinguished and that the reclosing operation is successful.

## Opening Operations: Chopping Overvoltages and Reignitions

In addition to the inductance of the winding, a shunt reactor always has some stray capacitance, in the windings, the bushings, and in the connecting leads. When a reactor is de-energized, the voltage across it will oscillate with the natural frequency determined by the inductance and stray capacitance. The oscillation frequency is typically a few kHz. Due to chopping (premature interruption) of the current slightly before the natural current zero, the oscillating reactor voltage will have higher amplitude than the supply voltage. For modern SF<sub>6</sub> circuit breakers, typical

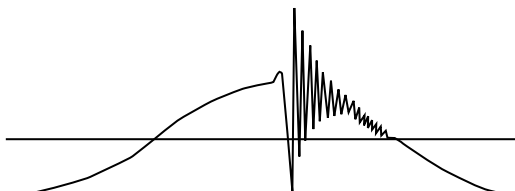
## Switching of Shunt Reactors

magnitudes of this “chopping overvoltage” are 1.2 to 2.0 p.u. with the highest values occurring for small reactors. The chopping overvoltage, with its limited amplitude and frequency, is normally quite harmless both for the reactor itself and for the surrounding system, see Figure 2.



**Figure 2.**  
Voltage across shunt reactor at de-energizing without reignition. Moderate chopping overvoltage and moderate oscillation frequency.

Due to the oscillating reactor voltage, there will be a high voltage stress across the circuit breaker. If the contact gap is still small, i.e. if the arcing time is short, the circuit breaker probably will reignite, see Figure 3. A reignition will generate high-frequency transients (typically hundreds of kHz) in both reactor voltage and current. Following a reignition, the reactor current will be interrupted again, either at a high-frequency zero of the current, or most probably at the subsequent power frequency zero.



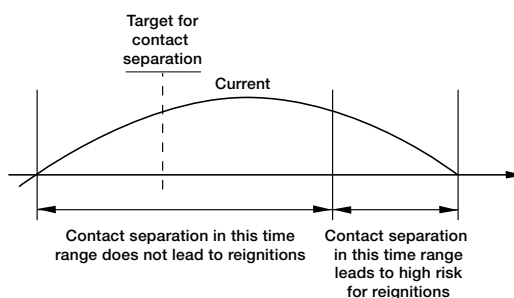
**Figure 3.**  
Voltage across shunt reactor in event of reignition. A high-frequency transient is generated.

The very steep voltage transients caused by reignitions will be unevenly distributed across the reactor winding, with the highest stress on the initial turns. There is a risk that the voltage stress will lead to puncture of the winding insulation in the reactor, which in the long run may lead to complete breakdown. Insulation of nearby equipment may also be damaged. Surge arresters will only protect to a limited extent, since the severity of the voltage stress is related both to the rate-of-change and to the amplitude.

### Control of Opening Operations

Switchsync™ controllers for shunt reactor circuit breakers are normally used for control of opening operations. Uncontrolled de-energizing will, in a typical case, cause reignition in at least one circuit breaker pole. By controlling the contact separation in such a manner that short arcing times will not occur, reignitions will be eliminated. The remaining voltage transient is a harmless chopping overvoltage with relatively low frequency. A normal value of the targeted arcing time is 5–6 ms, but for small reactors the targeted arcing time may even be longer than ½ cycle of the current. In this case, there will be no or insignificant re-ignition transients at the first current zero after contact separation, while final interruption, without re-ignitions, will take place at the second current zero of the same phase.

In most cases, there will be a large range of arcing times not resulting in re-ignitions, see Figure 4. For such cases, the adaptive function of the Switchsync™ controllers is unnecessary. However, by using the latest version of Switchsync F236 for controlled shunt reactor de-energizing with single-pole operated circuit-breakers unintended re-ignitions will be detected by the re-ignition detection function. For the consecutive opening operation an adjustment will be made such that the risk for a repeated re-ignition will be avoided. The re-ignition detection function is based on measurements of the load currents and programmed contact separation instants.



**Figure 4.**  
Target for contact separation in order to eliminate reignitions. End of next to last current loop may sometimes be used as target area for contact separation.

## Switching of Shunt Reactors

### Closing Operations, Inrush Current

Energizing of a shunt reactor may cause inrush currents with high asymmetry and long time constants. The actual magnitude of the inrush current is quite dependent on the range of linearity of the reactor core. Due to the air gaps utilized in shunt reactor cores there are no severe saturation effects.

In spite of their limited amplitude, reactor inrush currents may still have adverse effects. They may lead to zero sequence current, cause saturation of CT cores, with resulting nuisance tripping of relays, or cause other network disturbances.

### Control of Closing Operations

Controlled closing of shunt reactor circuit breakers is utilized in several cases, and normally as a complement to controlled opening.

The making target that gives the lowest reactor inrush current is the peak of the power frequency voltage across the circuit breaker, and this target is normally utilized. Making of the current in this case creates a transient voltage stress equal to that which occurs if the circuit breaker reignites at 1 p.u. voltage during a de-energizing operation. This voltage stress is normally acceptable but if such a voltage stress is considered unacceptable, an alternative procedure is to make the current at voltage zero across contacts. This will in principle lead to maximum inrush current. Zero sequence relays may then be set with time delay (or be set less sensitive), in order to avoid nuisance tripping. It is not possible to minimize both the inrush current and the transient voltage stresses at the same time.

### Three-pole Operated Mechanically Staggered Circuit Breakers




In a similar way as for controlled energizing of grounded shunt capacitor banks by means of three-pole operated mechanically staggered circuit breakers, it is for some reactor applications very important that the recommended pole - phase connections are followed.

Three-pole operated, mechanically staggered circuit breakers are designed with shortest possible time staggering to fit their applications. Shortest possible time staggering means that loads having uncoupled phases are switched in a controlled

manner in reverse phase order. This is the case for controlled opening of grounded and magnetically independent reactor loads.

The staggering will allow for a certain delayed action of the individual poles at the start of operation. The delayed start of an opening operation does not result in contact opening speeds, measured from the contact separation instants, that are below that for a standard pole. Therefore, the interrupting performance, compared to a standard pole, will be maintained.

Also of note is that it is impossible to combine controlled closing and controlled opening by means of three-pole operated mechanically staggered circuit breakers for loads having no inter-coupling between the phases. 

Circuit breakers with mechanical staggering and intended to switch grounded magnetically independent reactors are designed to interrupt in reverse phase sequence. The resulting mechanical staggering at closing will be reversed to that at opening, which means a pole closing order following the straight phase sequence. The optimum pole closing order, to minimize the zero sequence current, is to close in reverse phase sequence, which cannot be achieved.

For permissible connections of staggered circuit breakers, see the appendix. Please contact ABB Power Technologies, High Voltage Products, Ludvika, Sweden.



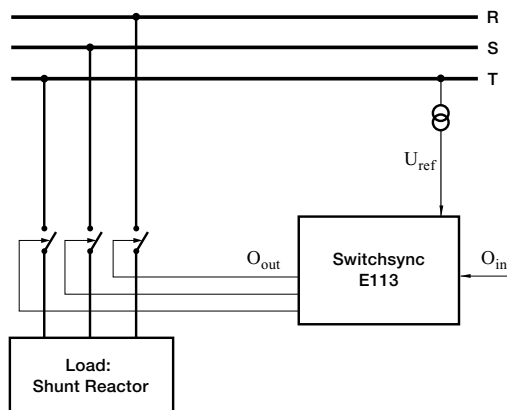
Shunt reactor, 420 kV, 150 Mvar

## Switching of Shunt Reactors

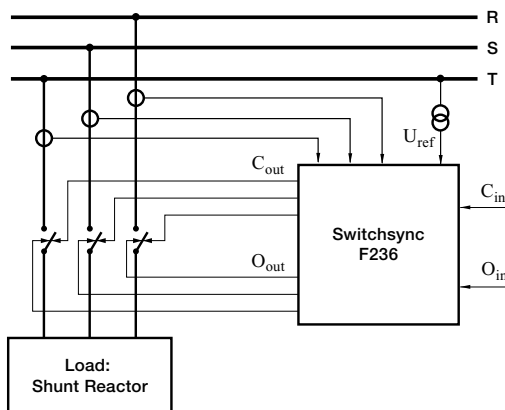
### Suitable Switchsync™ Controllers

Circuit breakers for shunt reactors are normally single-pole operated due to the high rated voltages. In cases with three-pole mechanically operated circuit breakers, controlled opening operations may be arranged by use of mechanically staggered circuit breaker poles. However, it is normally not possible to control both opening and closing operations with mechanically staggered circuit breakers.

#### Only opening; Switchsync™ E113

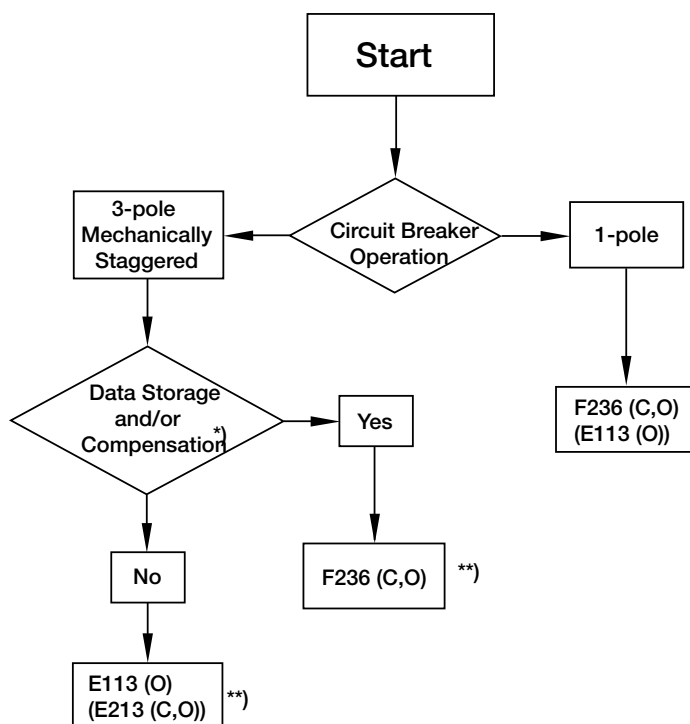


#### Both opening and closing; Switchsync™ F236



For legend, see Page D-4

### Switchsync™ Selection-tree Switching of Shunt Reactors



\*) Compensation for control voltage, temperature etc.

\*\*) Check that correct circuit breaker solution exists. (Combined controlled opening and closing is not possible for magnetic independent and grounded reactors)

# Switching of No-load Power Transformers

## Power Transformer Design

Three-phase power transformers may consist of three separate single-phase units, or be complete three-phase units with common core and tank. Common three-phase cores may be of either five-leg or three-leg design. The primary and secondary windings may be arranged in Y-(grounded or ungrounded) or D-configuration. Tertiary, D-connected windings are sometimes utilized in cases with Y-connected primary and secondary windings.

Depending on the core and winding arrangement, the individual phases may or may not influence each other during switching operations, and this has to be considered when controlled switching is applied. The phases will influence each other in the following cases:

- Ungrounded neutral on the switched side
- Three-leg core
- D-connected secondary or tertiary winding

A power transformer in no-load operation, i.e. with its secondary side unconnected, will consume only a few amperes of magnetizing current. For reasons of economy, the core material will be fully utilized, with magnetic flux reaching up to its knee point, and the magnetizing current therefore normally having a pronounced non-sinusoidal shape.

## Relation between voltage and flux

The relationship between coil voltage and core flux is:

$$\Phi = \int U dt$$

Therefore, in steady state condition the generated symmetrical flux will lead the voltage by 90 electrical degrees. The symmetrical flux will then in its turn result in a symmetrical minimized magnetizing current determined by the magnetic characteristic of the core.

For a single-phase transformer in steady state condition the relations between voltage, flux and current are graphically illustrated in Figure 1.

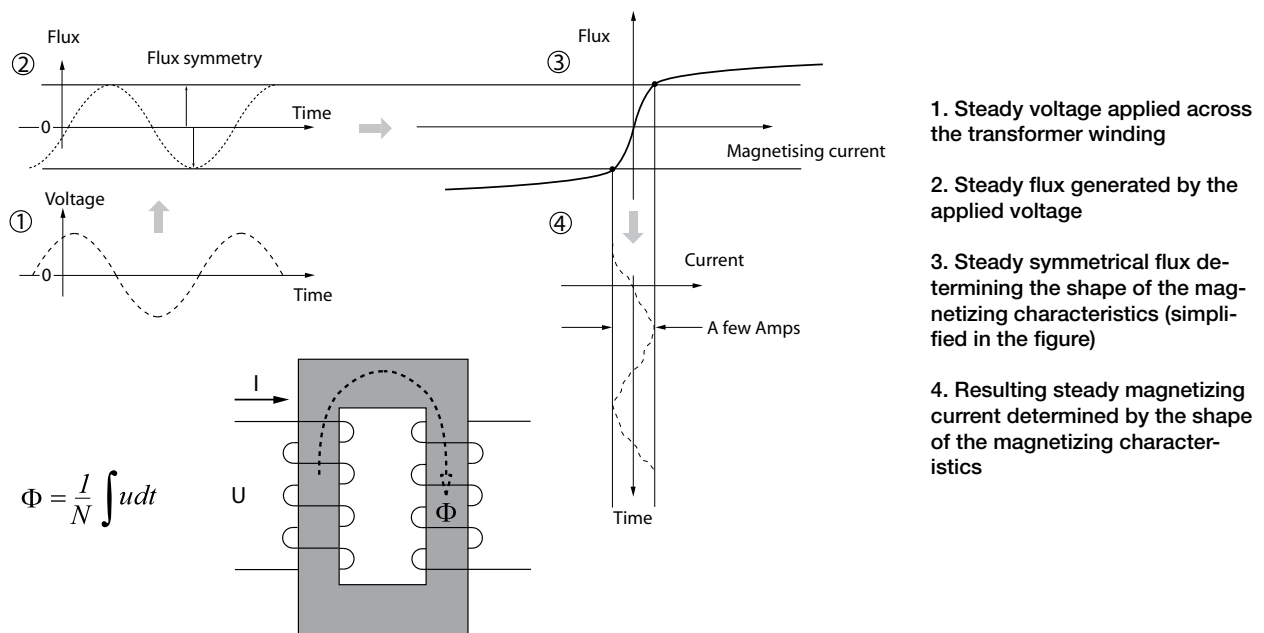
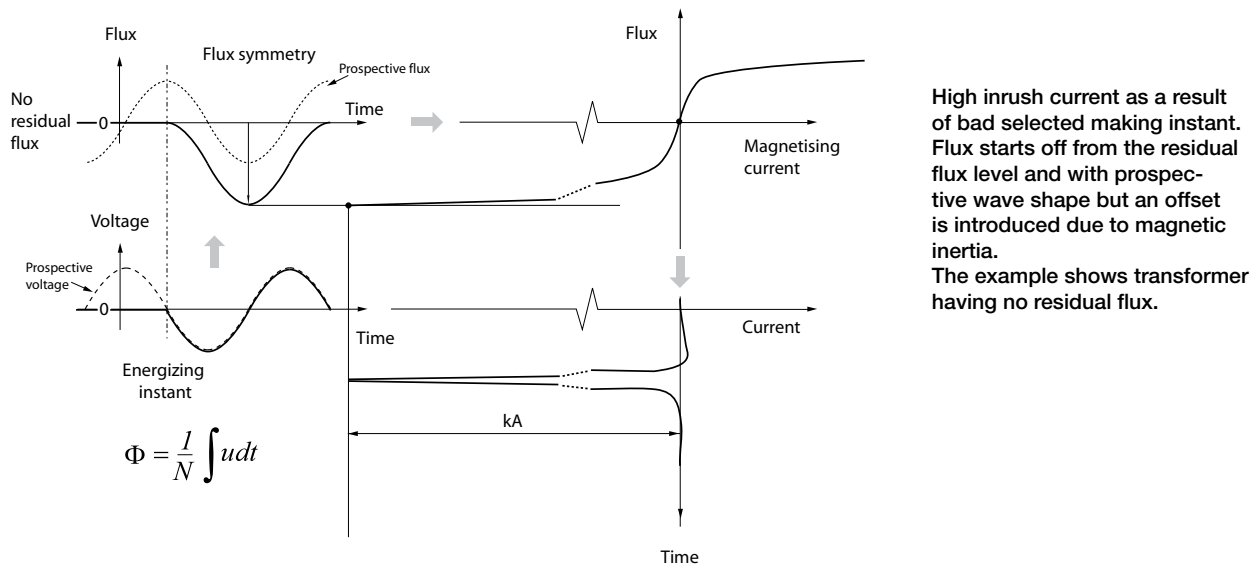


Figure 1.  
Power transformer in steady state no-load condition

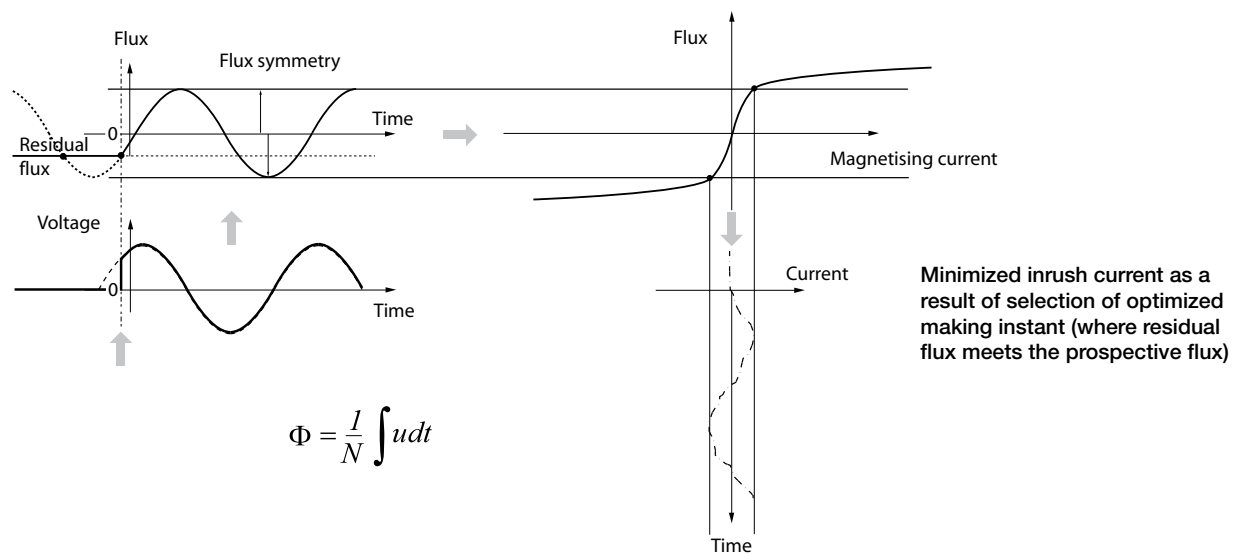
## Switching of No-load Power Transformers

Flux asymmetry may be introduced at energizing by making at unfavorable instants and due to magnetic inertia as shown in Figure 2.



**Figure 2.**  
High inrush current resulting from bad selected making instant.

The solution to create flux symmetry at energizing (to imitate the steady-state condition) is to make at instants where the prospective flux meets the residual flux. An example of an energizing intended to result in flux symmetry is shown in Figure 3. The transformer is energized at an instant where the prospective flux equals the residual flux.



**Figure 3.** Ideal making instant taking into account the residual flux

The described method requires that the residual flux level is known by measurement (integration of the load side voltages at interruption) or has been determined by a previously performed controlled interruption. It is assumed that the residual flux remains unchanged from the de-energizing until the next energizing.

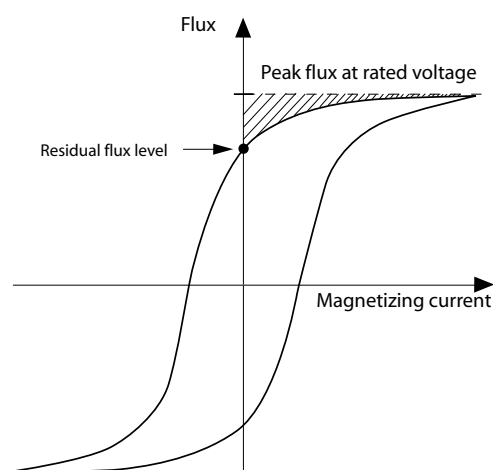


# Switching of No-load Power Transformers

## Opening Operations

No-load transformer currents are relatively small, and current chopping effects are therefore more pronounced than for corresponding interruption of shunt reactors. The natural oscillations of the transformer windings, however, are much less pronounced and more strongly damped. Therefore, the overvoltages generated during opening operations are low in amplitude and normally considered quite harmless. For limiting overvoltages, controlled opening operations are thus not needed.

After interruption, a residual flux may remain in the transformer core and influence the subsequent making conditions. Interruption at natural current zero will lead to the lowest residual flux. However, since the no-load current is so small, it may quite easily be chopped by the circuit breaker relatively far from natural current zero, and this may lead to high residual flux, see Figure 4.



**Figure 4.**  
Magnetic flux in transformer core at rated voltage

In certain cases, when the connecting leads to the transformer have sufficient capacitance, interruption may be associated with a damped oscillation (related to the transformer inductance and the surrounding capacitance). Such oscillation will decrease the residual flux towards zero.

## Control of Opening Operations

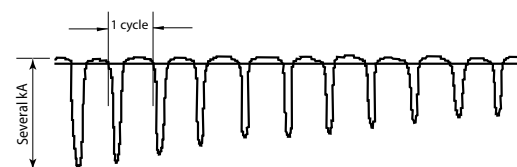
In situations where there may be residual flux, controlled opening operations may be utilized to control its magnitude and polarity. By using controlled opening operations as a support for the subsequent controlled closing operations, the inrush current can be limited even further.

## Closing Operations: Inrush Current

The magnetic flux in the transformer core is proportional to the integral of the voltage across a winding. Under steady state conditions, both voltage and flux are symmetrical and sinusoidal, as exemplified in Figure 1.

The situation may be quite different when energizing the circuit at an unfavorable instantaneous voltage value. In a single-phase case, and disregarding residual flux, the worst situation would be when making occurs at voltage zero, see Figure 2. In this case, the flux is initially forced up to a peak value twice as high as in stationary operation, it will be highly asymmetrical and only slowly attain its normal symmetrical shape. Consequently, the core will be driven far into saturation, and the corresponding current – the inrush current – will be extremely asymmetrical and non-sinusoidal, see Figure 5. Depending on the polarity, any residual flux in the core at the instant of energizing may add to the flux related to the voltage, and make the situation even more severe.

A typical inrush current may have peak values reaching several kA. The result is mechanical stress on the transformer windings, interference on secondary circuits from high zero-sequence current, and network disturbances by current harmonics.



**Figure 5.**  
Inrush current at not controlled energizing of unloaded power transformer

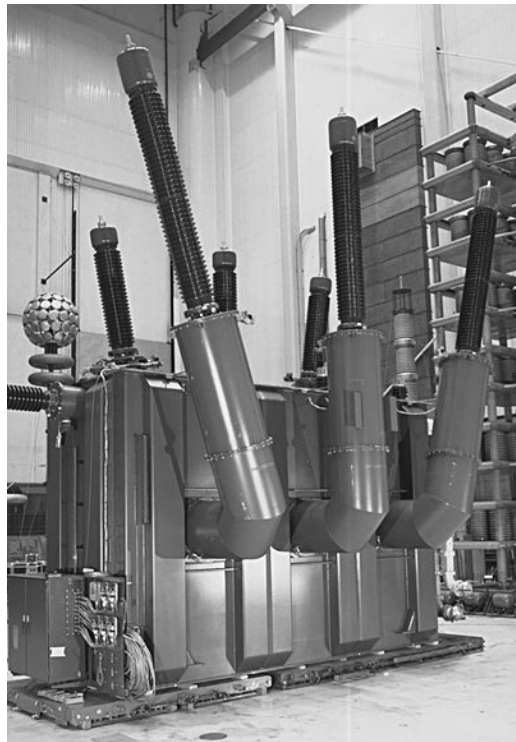
# Switching of No-load Power Transformers

## Control of Closing Operations

Switchsync™ controllers for transformer circuit breakers are used for control of closing operations, in order to limit inrush currents.

The closing operation should be initiated at an appropriate time instant in consideration to the residual flux of the transformer core. The goal is to make the flux in the core symmetrical from the start. Disregarding residual flux, the general principles in achieving this goal may be summarized as:

- The first making should be made in one phase, if the neutral of the primary winding is grounded, or in two phases if the neutral is ungrounded. Making should occur at maximum phase-to-ground voltage (grounded neutral) or maximum phase-to-phase voltage (ungrounded neutral).
- Making of the remaining phase or phases should occur at an instant when the flux in the corresponding cores resulting from the first making is the same as the flux that will circulate in these cores under steady state conditions.



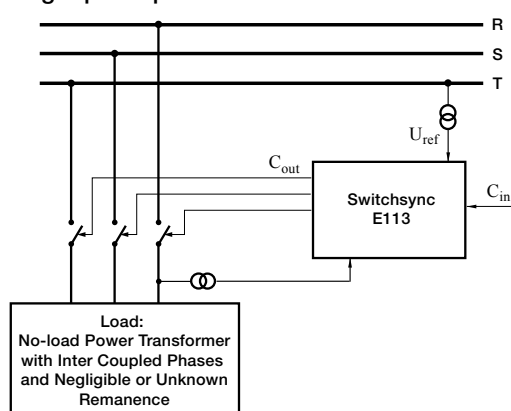
420:132 kV, 750 MVA transformer in test area, Ludvika, Sweden

# Switching of No-load Power Transformers

## Control of Closing Operations, Residual Flux Disregarded.

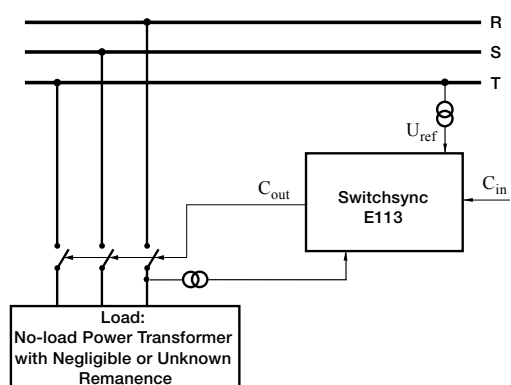
When residual flux may be disregarded, it is sufficient to control the closing operations by means of the Switchsync E113 only. This straight-forward method will limit the highest inrush current magnitudes even if there should be residual flux. For this reason, it may also be applied in cases with residual flux - or with unknown residual flux - even though better results are obtained by use of the Switchsync F236 or T183, and the associated methods with controlled opening and closing operations or determination of the residual flux respectively.

### Single-pole operated circuit breaker



**Note:** Coupled phases lead to simultaneous voltage start in the three windings. Therefore, only one adaptation signal is needed (can be used).

### Three-pole mechanically staggered operated circuit breaker



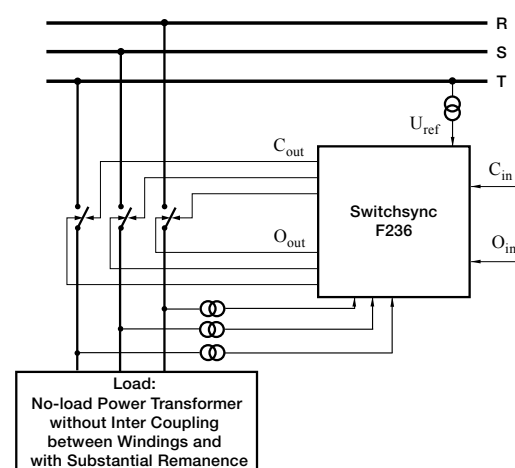
**Note:** Voltage signal, from the first energized winding, is used for the adaptive function of the controller. For circuit breakers seldom operated, however, compensation may be a better solution than adaptation control since a substantial change of ambient conditions may appear between two consecutive operations. For permissible connections of staggered circuit breakers, see separate appendix.

## Control of Closing Operations, after Controlled Opening Operations

The opening operations of the breaker are controlled in order to achieve a defined and repeatable residual magnetic flux in the transformer core. The procedure is normally to interrupt the no-load current close to a natural zero passage, which results in minimum flux in the core. The subsequent closing operation is then controlled in order to minimize the inrush current, based on this knowledge. Sometimes, however, a higher value of residual flux is chosen, as this will be associated with lower pre-arcing stress of the circuit breaker at the subsequent closing operation. This also improves the precision of the targeting process.

The method is suitable for regular planned switching of transformers under no-load conditions. It is applicable in situations where the same circuit breaker will always perform the making and breaking operations. If a transformer could be switched by different circuit breakers from time to time, such as in double breaker or breaker-and-a-half configurations, control logic must be applied to ascertain that the same circuit breaker will also perform the next energizing operation. A suitable controller type is the Switchsync™ F236.

The circuit breaker should be single-pole operated. Three-pole operation is unsuitable since relevant mechanical staggering cannot be arranged.

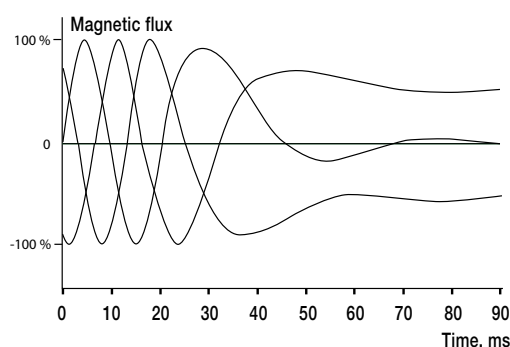


**Note:** In cases when the transformer windings are inter-coupled, it is sufficient to arrange voltage measurements for the adaptive function in one phase only.

# Switching of No-load Power Transformers

## Control of Closing Operations after Random Opening Operations

Opening operations are performed at random, while the resulting residual flux is determined by integration of the transformer voltage, see Figure 6. The voltage signals to the controller for this process may be taken from normal VTs or CVTs adjacent to the transformer.



**Figure 6.**  
Residual flux at interruption determined by integration of transformer voltage. The windings are D-connected and therefore the three residual fluxes add up to zero.

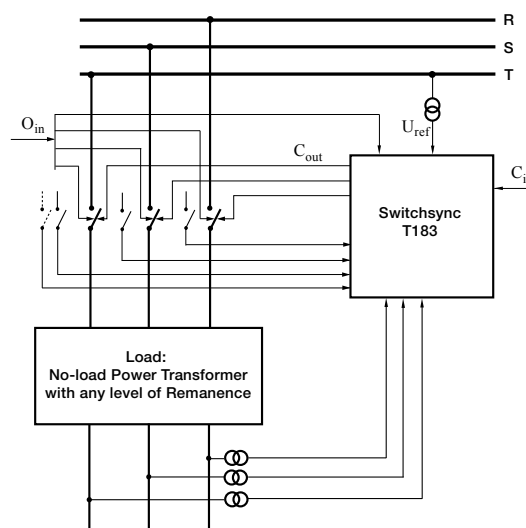
At de-energizing of a transformer by a multi-unit circuit breaker having voltage grading capacitors the integral of the load side voltages will not attain a final steady state level due to the voltages coupled through the capacitors. Therefore the residual flux is determined as an average value during a certain time after interruption.

Based on the calculated residual flux, the subsequent closing operation is then controlled in such a manner that the inrush current is minimized. In this mode of operation, the residual flux may vary considerably from one operation to another and the actual controlled making operations will take place at varying time instants in relation to the supply (reference) voltage.

The method is mainly suitable for situations with unplanned operations, under varying switching conditions and also works when opening operations occur in connection with faults in the system. Since each pole needs to be controlled independently, the method requires single-pole operation of the circuit breaker. A suitable controller type is the Switchsync™ T183.

The adaptive function of the controller must be used in order to attain sufficient accuracy. Signals are obtained from precision auxiliary contacts on the circuit breaker. The dielectric properties of the circuit breaker at closing (RDDS, Rate of Decrease of Dielectric Strength) must be known, and are used when programming the controller.

The method relies on appropriate signals from voltage transformers to determine the residual flux. There are, however, some combinations of transformer winding arrangements and positions of voltage transformers that do not permit determination of the residual flux. In these cases, the method is not applicable. See the separate table on page O-1.



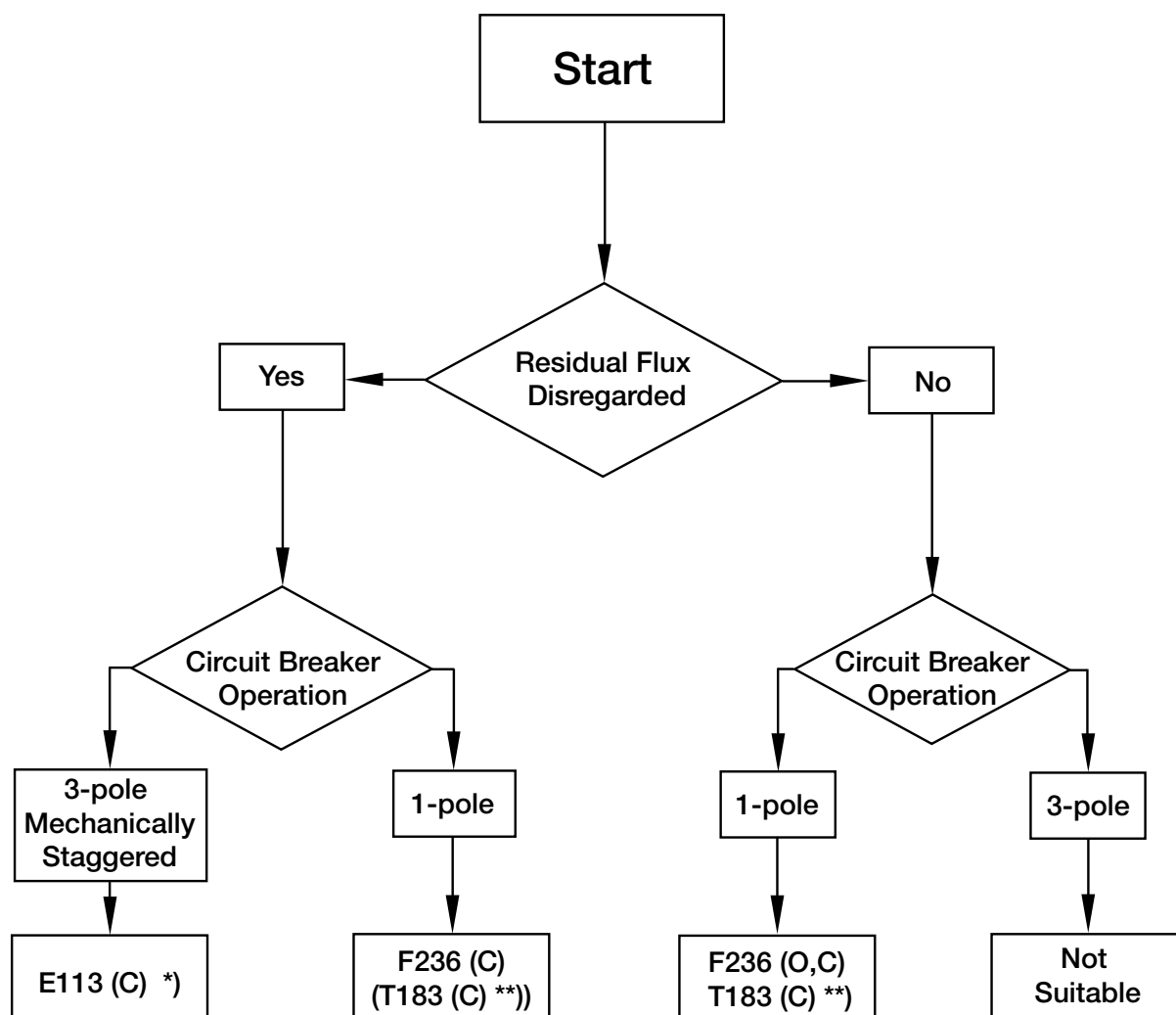
**Note:** When controller type T183 is used for controlled energizing of an unloaded transformer, the interruptions will not be controlled. However, the trip signal going directly to the circuit breaker poles must also be given, in parallel, to the controller. This trip information is needed to inform the controller that it should finalize the flux determination.

For legend, see Page D-4

Transformers and strategies treated in this chapter only refer to switching of one transformer (three single-phase units or one three-phase unit). For some applications, parallel transformers (of different kinds) may be switched by one circuit breaker. This may be the case for HVDC converter circuit breakers, where a transformer group consisting of a grounded Y - ungrounded Y transformer is connected in parallel with a grounded Y / delta connected transformer.

# Switchsync™ Selection-tree

## Switching of No-load Power Transformers



\*) Check that correct circuit breaker solution exists

\*\*) Adaptation control requires precision auxiliary contacts

## Switching of No-load Power Transformers

Customer's  
Notes

# Switching of Transmission Lines

## Closing and Reclosing Transients

When an overhead line is energized by closing the line circuit breaker, switching transients will be generated mainly on the line, but also in the supply network. The switching transients depend on the difference between the supply voltage and the line voltage at the instant of energizing, and are related to traveling wave phenomena on the line. Such switching transients are a concern on many transmission networks at rated voltages of 420 kV and above, and especially in regards to long lines. For these high voltages, the switching impulse withstand voltage of the system and equipment will only be about 2-3 p.u. and switching overvoltages have to be kept under control.



A traditional method of limiting these switching overvoltages to acceptable levels is to use circuit breakers equipped with preinsertion resistors. The resistors give efficient limitation of the switching overvoltages, but make the circuit breakers mechanically more complex and costly.

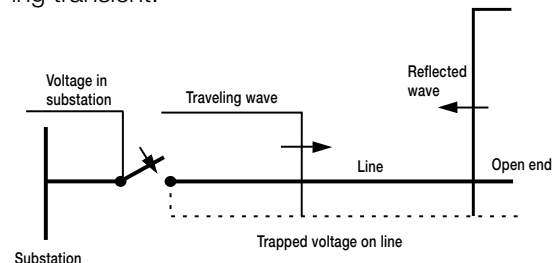
Controlled closing and reclosing of line circuit breakers using Switchsync™ controllers eliminates the need for preinsertion resistors. The limitation of the switching overvoltages – especially when used in combination with surge arresters – is similar to what is achieved with preinsertion resistors.

The voltage on the line before closing or reclosing operations will vary from case to case.

Upon planned closing operations there will be no charge on the line. Sufficient time has passed since the line was previously energized and all trapped charge will have had sufficient time to decay for zero.

Upon three-phase reclosing operations (normally after clearing of a single-phase fault on the line) with uncompensated overhead lines, there may be more or less trapped charge on the healthy phases, with corresponding DC voltage. Such trapped charge may normally be disregarded in cases with magnetic voltage transformers connected to the line, due to their low resistance to ground. With capacitive voltage transformers, however, the resistance to ground is high, and trapped charge may remain on the line for a considerable time up to several seconds.

Figure 1 shows the principal situation for an uncompensated line with trapped voltage during a reclosing operation. When, as indicated in the figure, energizing occurs at an instant with a large difference between (instantaneous) supply voltage and line voltage, a large traveling wave will be injected onto the line. When this wave reaches the open, far end of the line, it will be reflected and a high overvoltage will be initiated. Controlled reclosing of the circuit breaker aims to minimize the initial voltage difference between the supply and the line, and thereby the switching transient.

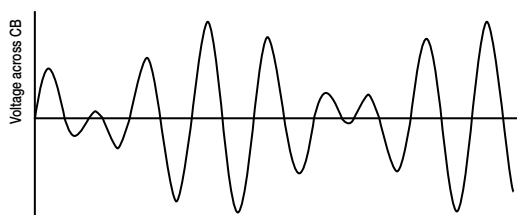


**Figure 1.**  
Principle of traveling waves at energizing of an uncompensated line at an unfavorable instant.

At reclosing operations of shunt compensated lines (shunt reactor connected on the line side of the circuit breaker), the voltage on the line will be a gradually damped sinusoidal oscillation, with a frequency determined by the line capacitance and the inductance of the shunt reactor. The frequency will generally be lower than the frequency of the supply voltage. As a result, there will be an amplitude modulated voltage oscillation across the open circuit breaker, with the actual shape determined by the degree of compensation of the line. See Figure 2.



# Switching of Transmission Lines



**Figure 2.**  
Example of voltage shape across the open circuit breaker before reclosing of a shunt compensated line.

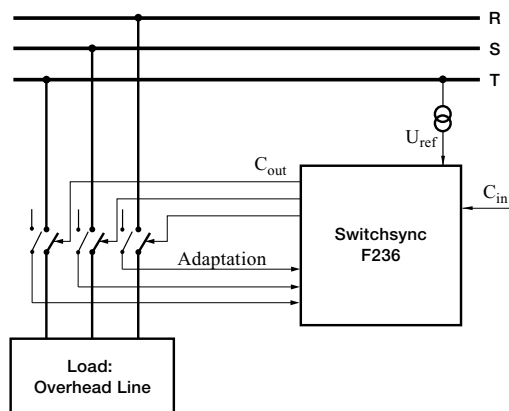
## Control of Closing and Reclosing Operations, Uncompensated Lines

For uncompensated lines, controlled switching of the line circuit breakers may be arranged in two different ways. Both methods require use of single-pole operated circuit breakers:

### 1. Use of Switchsync™ F236

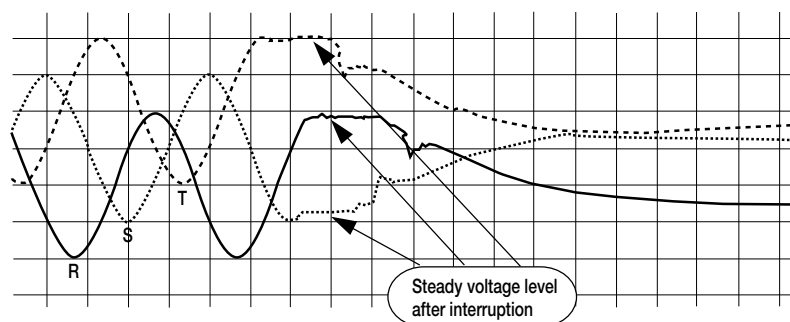
Trapped charge on the line, resulting from the opening operation, is not recorded.

For closing, a compromise strategy is used that determines the targets for contact touch by a certain delay after supply side phase-to-ground voltage zero. The delayed targeting is determined by the circuit breaker RDDS (Rate of Decrease of Dielectric Strength) with respect to the amplitude of the system voltage and its frequency. In this manner, limitation of high overvoltages is achieved irrespective of the actual trapped charge. This is a straightforward method, and the resulting overvoltage level is often acceptable, especially when applied in combination with surge arresters. In many cases, the trapped charge will actually be zero or close to zero. This will be the case when sufficient time has elapsed from the opening operation, or even at re-closing operations, if the line is equipped with magnetic voltage transformers. The method gives best results with circuit breakers having high RDDS.

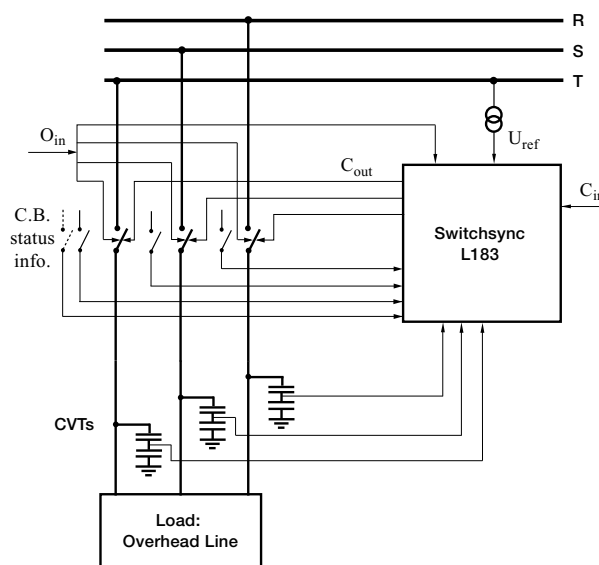


### 2. Use of Switchsync™ L183

More efficient limitation of switching overvoltages is achieved when the trapped charge on the line is recorded, and taken into consideration by the controlling device. This solution is especially useful in situations when considerable trapped charge is to be expected; i.e. for reclosing operations in situations when CVTs are used. The initial magnitude of the trapped charge can be recorded by the CVTs. As shown in Figure 3, the CVTs will show the DC voltage level, related to the trapped charge for a certain time interval after interruption, and this value will be used by the controller. Should the time interval before reclosing exceed 20 s, the controller will automatically change to the assumption that the line is uncharged.



**Figure 3.**  
Voltage signals from CVTs during interruption of an unloaded uncompensated healthy line. The magnetic circuit in the transformer part goes into saturation after a certain time. The transient response classes for CVTs may differ but the algorithm used by controller L183 is suitable for determination of the trapped line voltage independent of CVT class.



For legend, see Page D-4

# Switching of Transmission Lines

## Control of Closing and Reclosing Operations, Shunt Compensated Lines

For shunt compensated lines, the interaction between line capacitance and reactor inductance will lead to voltage oscillations of the healthy phases after interruption. In this case, due to the oscillating voltage shape on the line, the voltage transformers connected to the line will provide correct voltage signals.

Controlled switching requires use of single-pole operated line circuit breakers. Reclosing may be set to occur slightly after (time depending on RDDS) phase-to-ground supply side voltage zero. A suitable controller is the Switchsync™ F236, connected in the same manner as for uncompensated line.

## Control of Closing and Reclosing Operations, Series Compensated Lines

For the time being, no suitable method is available for limitation of switching overvoltages on series compensated lines by use of controlled switching.

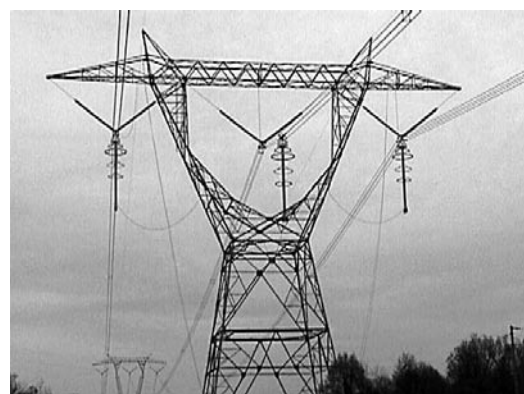
## Reduction of Overvoltages when Using Controlled Line Switching

The actual limitation of switching overvoltages that will be achieved by use of controlled line switching depends on several factors, such as:

- line length and configuration
- degree of compensation
- single- or three-pole reclosing
- type of Switchsync™ controller utilized
- position and type of surge arresters

The acceptable switching overvoltage level depends on the insulation level of the system.

Due to the variation of parameters, the choice of Switchsync™ controller must be made on a case-by-case basis, and often requires a study of the switching overvoltages that may occur. ABB is prepared to participate in such studies. The best solution is often a combination of Switchsync™ controller and surge arresters. Such surge arresters may be placed at line ends, as a normal part of the protection system for the substations, but may also be placed along the line. See Figure 4.



**Figure 4.**  
Transmission Line arresters (PEXLINK) in an 800 kV system, USA. Utilized for limitation of switching overvoltages.

An example of the variation of switching overvoltage limitation achieved with different combinations of Switchsync™ controllers and surge arresters is shown in Figure 5. Use of Switchsync™ control gives adequate overvoltage reduction, without need for pre-insertion resistors and the related complexity of the circuit breakers.

Solutions with Switchsync™ control are particularly beneficial in breaker-and-a-half configurations, where a circuit breaker may switch different objects, e.g. sometimes a transformer and sometimes a line. In such cases, it may be difficult to choose pre-insertion resistors that are suitable for both applications.

## Switching of Transmission Lines

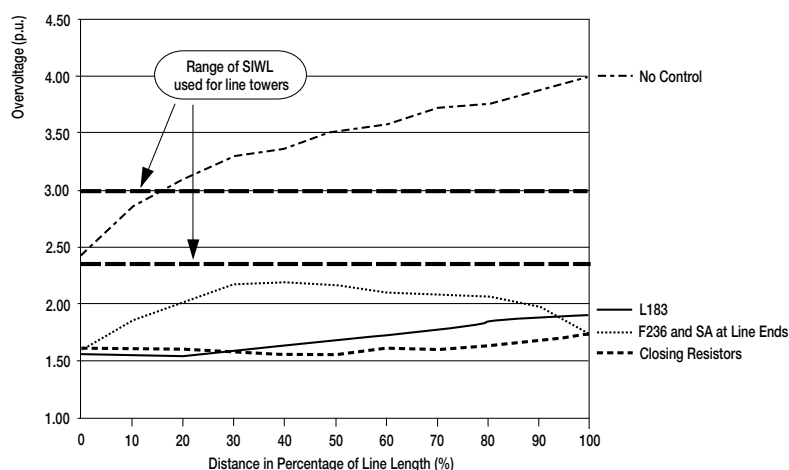
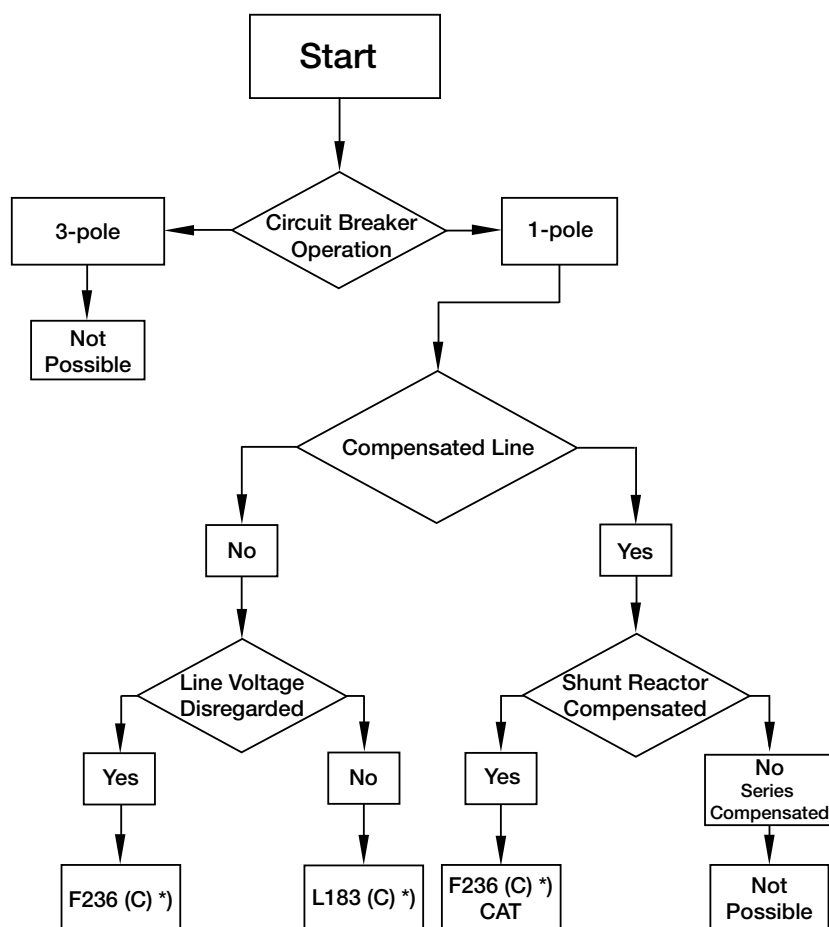


Figure 5.  
Overvoltages for different combinations of Switchsync™ controller and surge arresters (SA).  
Three-pole reclosing of 550 kV, 200 km, uncompensated line after single-phase ground fault.

### Switchsync™ Selection-tree Switching of Lines



\*) Adaptation control requires precision auxiliary contacts

# Adaptive Functions

## Adaptation Control

All Switchsync™ controllers are equipped with special functions to control the result of a controlled switching operation.

The adaptation control can be arranged in different ways and for both controlled closing and controlled opening.

Deviations from the intended targets may be caused by variations in the operating conditions. The operating conditions that may cause changes of the circuit breaker operating times are, for example, gradually increasing contact burn-off caused by many switching operations, change of ambient temperature and variations of the auxiliary voltage.

The functioning principle of the adaptation control is that a detected error from the target will be compensated for in the next controlled operation.

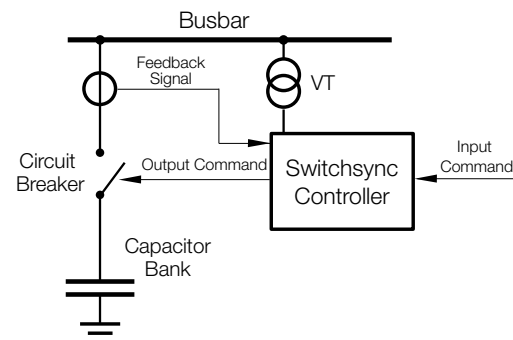
If the circuit breaker should have a change in operating time from the value assumed by the Switchsync™ controller, then the adaptation feedback signal from a sensor or transducer will appear either slightly later or earlier than expected. When an error has been observed by the controller, the internally created waiting time will be modified for the next operation in such a way that the circuit breaker will be guided back to the intended target

## Adaptation Control on Closing Operations

The ultimate target for controlled closing is the intended energizing instant. The optimum way of supervising the energizing instant is to note the phase angle at which the circuit breaker starts to pre-strike with respect to the selected reference.

This kind of control can easily be arranged by receiving the current start signal(s), CURRENT DETECTION, from a current transformer. As an alternative the voltage onset instant(s) can be detected by means of a voltage transformer behind the circuit breaker, VOLTAGE DETECTION.

A typical arrangement for detection of current start is shown in Figure 1.



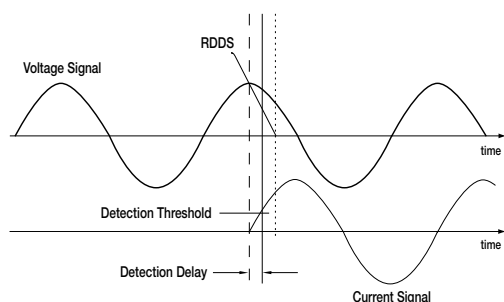
**Figure 1.**  
Example of shunt capacitor bank energizing with current start feedback loop.

Note: A certain detection delay must be taken into account if current start detection is used and when the current starts sinusoidal (reactor energizing applications). The detection threshold depends on the amplitude of the secondary current.

*It should also be noted that coupled phases (for example YNd-transformers, having a secondary delta winding) will cause simultaneous voltage start in all phases when only one pole has energized its winding.*

If no instrument transformers are available, it is still possible to supervise the result of a controlled closing operation by detecting the contact touch instant(s) of the circuit breaker. In this application, the VOLTAGE DETECTION function will be used and the signal will be given by a precision auxiliary contact. Note that the contact touch instant differs from the energizing instant by the pre-arcing time; see Figure 2.

## Adaptive Functions



**Figure 2.**  
Example of single-phase reactor energizing.  
Current should start at peak voltage.

Real and intended energizing instant marked by dashed line to the left.  
Contact touch instant marked by dotted line to the right (pre-arcing time = time between energizing instant and contact touch).  
Detection delay, to be programmed, shown by continuous line.

For single-pole operated circuit breakers, the adaptation control can be arranged for each pole individually.

In the case of three-pole operated circuit breakers with mechanical staggering, only one pole will be supervised. The other two poles are mechanically linked to the controlled one.

### Adaptation Control for Opening Operations

In most cases of controlled opening, the target consists of a wide range of arcing times and not a single instant. Therefore, the need of adaptive control is of less importance compared to that for controlled closing having high demands on precision to make the current at the correct moment.

If controlled opening is applied, there are two options depending on the type of operating mode and type of controller.

The first option is to detect the contact separation instant(s) with respect to the selected reference. This must be arranged by the use of special precision auxiliary contacts. The already present auxiliary contacts are normally not accurate enough. The auxiliary contact arrangement shall be arranged so that a voltage signal will be given to the controller upon its activation. This method is not reflecting the result of the interruption.

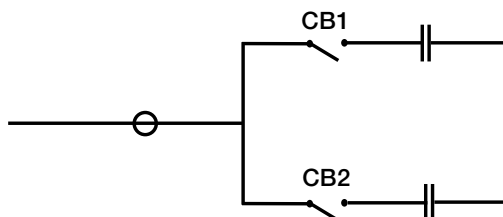
The second alternative is to use the signal from the current transformers in the load branch. The intended interrupting instants are known by the controller (by its inputs). If current is still flowing 1/4 of a cycle or more after intended interruption, this will be detected and corrected for in the next controlled opening operation. Possible with Switchsync™ F236.

### Adaptive Function of Switchsync™ E113, E213 and F236

Using any of these devices for controlled closing makes it possible to adapt at energizing instant(s) by detection of current or voltage onset instants.

*NOTE: For controlled transformer energizing in adaptive mode using instrument transformer signals, voltage start detection (not current start detection) is required. At optimum targets, the current transformer output will be far too low and the current harmonics will introduce an unpredictable detection delay.*

Switchsync™ Controllers E113, E213 and F236 can also be programmed to operate in a special mode to detect current change. This is a useful operating mode when only one current transformer supervises two shunt capacitor banks that are switched by separate circuit breakers; see Figure 3.



**Figure 3.**  
Example of arrangement where adaptation control of current change detection can be applied for the controller of the last closing circuit breaker.

For single-pole operated circuit breakers controlled by either the Switchsync™ E113 or E213 there will be one true adaptation for one pole while the adaptation control for the other two poles will be dependent.

## Adaptive Functions

Controlled opening by means of the E113 or E213 requires an auxiliary contact signal mirroring the contact parting instant(s).

Using the E213 for combined controlled closing and controlled opening excludes the use of adaptation control for opening. Priority will automatically be given for adaptation control on closing.

Controlled opening in adaptive mode when using the F236 can be arranged individually for each pole and by supervising the result of the interruption. This feature can only be used at reactor de-energizing since a reignition or restrike at de-energizing capacitive loads does not necessarily result in a full additional current loop.

### Adaptive Function of Switchsync™ L183 and T183

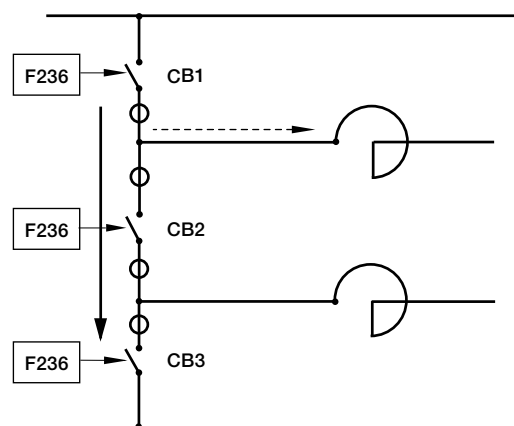
When using Switchsync™ L183 or T183 controllers there are no fixed energizing targets; instead they will depend upon the interrupting conditions reached at the latest interruption.

Therefore, it is not possible to adapt at fixed load onset instants. Adaptation control must be arranged by means of precision auxiliary contacts supervising the contact touch of the circuit breaker.

### Impact of Substation Configuration on Adaptation Control Arrangement

The tolerances for the adaptation signal shall be noted. The substation layout may call for special solutions in some cases.

Figure 4 shows an example of a circuit breaker and a half scheme with controlled reactor circuit breakers. In this example, all current transformers are installed outside the reactor bays.



**Figure 4.**  
Circuit breaker and a half scheme with CTs outside reactor bays.

The current start signal (dashed) when energizing a reactor may be appropriate, and well within the current start signal range (0.5 - 5.0 Arms).

However, the problem here is that the reactor current (dashed) will be low compared to the rated current flowing between the busbars (continuous) when they are interconnected.

The CT secondary current flowing through the controller after energizing the reactor may be amplified several tenths when the rated current flows between the busbars. A high enough current start signal may result in overcurrent when all circuit breakers are closed.

This arrangement will require special control circuits and must be thoroughly checked. The current transformers shall preferably be installed in the reactor bays.

Customer's  
Notes



# Impact of Substation Configuration

## Substation Configurations

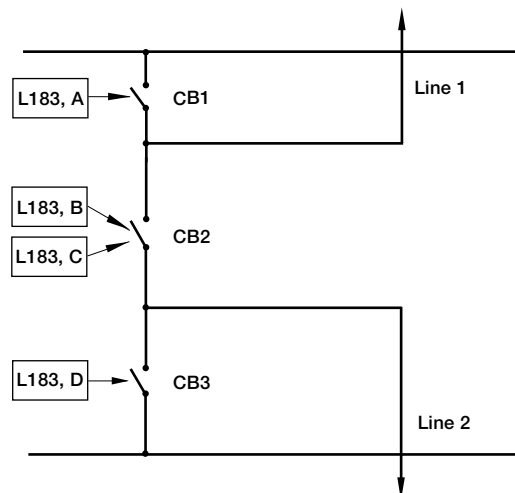
Generally, every circuit breaker to be controlled will need its own controller. However, in some substation configurations one circuit breaker may switch two different loads, which may call for more than one controller per circuit breaker.

In most cases, a specific load is switched by its own circuit breaker. In some substation configurations, one load may be alternatively switched by different circuit breakers.

The following two conditions call for special care.

- One load switched by two circuit breakers
- Two different loads alternatively switched by the same circuit breaker

A typical example where special attention is required is shown in Figure 1. The figure shows a circuit breaker and a half substation layout and two outgoing uncompensated transmission lines:



**Figure 1.**  
Circuit breaker and a half scheme in which one load may be switched by two alternative circuit breakers, but also where two different loads may be switched by one circuit breaker.

The example shown above illustrates two complexities. The first is that one circuit breaker may switch two different loads. Another complexity is that one load may be switched by two different circuit breakers.

To arrange for full operational flexibility in a scheme as shown in the figure, circuit breaker CB2 requires two controllers (B and C). The source side reference when switching in Line 1 will be the line side voltage of Line 1. Furthermore, the line side voltage of Line 1 will become the guiding reference when switching in Line 2 (only one reference and only one load, three load side voltages, can be connected to each Switchsync™ L183 controller).

The normally used busbar voltage as reference for controllers B and C may be inaccessible (if any of the busbars are out of service).

Separate commands, depending on which line is to be energized, must be given to the specific controller.

In the example, there will also be a non-altering of the adaptation control information for the controller (B or C). Controllers not receiving an input command do not upgrade the adaptation information.

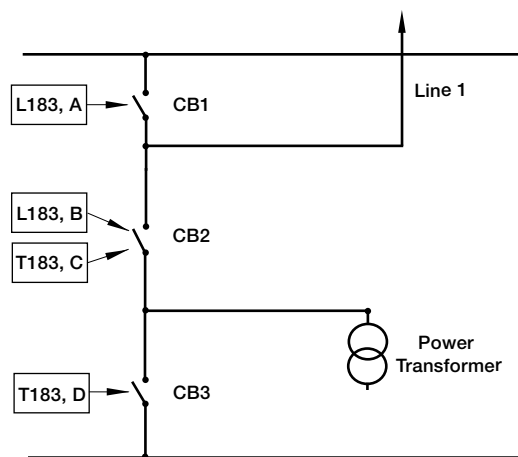
Auto-reclosing can easily be handled by both line circuit breakers (CB1 and CB2, or CB2 and CB3) if the trip information is given to both controllers (A and B, or C and D) and if the interrupting times do not differ by more than 150 ms.

Here it should also be noted that the circuit breaker(s) at the other end of the line must interrupt no later than 150 ms after the local circuit breaker(s). The line voltage would otherwise be unknown to the controllers in the reclosing circuit breaker.

If in Figure 2, Line 2 is replaced by another type of load, such as a transformer, the two lower controllers (C and D) should be T183s as shown in Figure 2.



# Impact of Substation Configuration



**Figure 2.**  
Circuit breaker and a half scheme with one outgoing line and one transformer

An additional complexity now arises in respect to operational conditions. Assume that the transformer is connected only to the lower busbar (CB2 is already open) and will be switched off temporarily.

The trip command can be issued to both controllers C and D but the residual flux will only be read by controller D since the C controller is informed that circuit breaker CB2 is already open.

This must be handled by operational conditions, requiring that the de-energizing circuit breaker must be the energizing one.

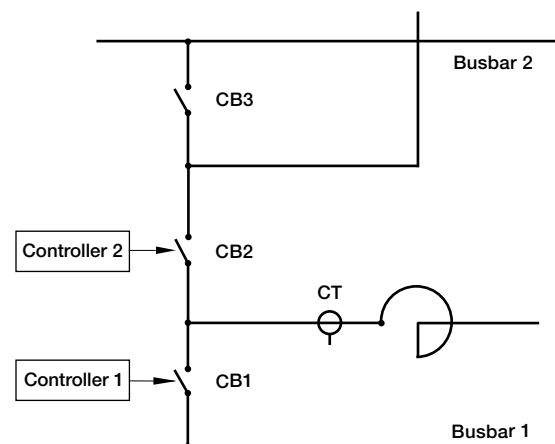
Having a circuit breaker and a half substation configuration and loads, intended to be switched in a controlled manner and having well defined and predetermined conditions (shunt capacitor banks and or shunt reactors) the substation layout does not present any control severities. However, the central circuit breaker still needs two controllers if the loads on each side are of different types. If sensors for adaptation control are in the switched bay, the adaptation control arrangement will work fully for all circuit breakers except CB2. Upgrading of adaptation information for CB2 controllers will change only for the controller receiving the input command.

If the operational conditions are such that switching will be rare, the advantage of adaptation control is also less. As an alternative, external parameter compensation can be installed.

Other examples of controlled circuit breakers requiring special consideration are bus couplers used to switch different kinds of loads.

Double busbar circuit breaker schemes, with the same load switched alternatively by two circuit breakers, are normally straightforward and do not require special consideration.

Special care should be taken when applying the adaptation control feature based on re-ignition detection. This is the case if the reactor can be energized from two sides and where the CTs are common, for example in the reactor bushings. An example of such an installation is shown in Figure 3:



**Figure 3.**  
Shunt reactor installation in a CB and a half substation and with CT for adaptation control in the reactor bushings.

In the given example current will always be measured by the CT as long as any of the two circuit breakers CB1 or CB2 is conducting. The only way to use the re-ignition detection function here is to arrange a fixed switching order and to set the function disabled for the controller of the first shunt reactor breaker to open.

## Impact of Substation Configuration



Disconnecting circuit breaker for controlled power transformer switching in a 420 kV substation

## Example of Circuit Breakers with Staggered Poles

Choice of Three-pole Operated Circuit Breaker with Staggered Poles, Existing Versions								
Type of Operation	Circuit Breaker Designation	Load	Electric Circuit of Load	Magnetic Circuit	Frequency (Hz)	Staggering for Intended Operation. (ms)		
						Pole A	Pole B	Pole C
Closing	LTB 72.5-170D1/BUS	Capacitor	Y-N and Delta		50	5	0	0
	HPL 72.5-300B1US				50	5	0	0
	LTB 72.5-170D1/BUS				60	4.2	0	0
	HPL 72.5-300B1US				60	4.2	0	0
	LTB 72.5-170D1/BGS		Y-0		50	6.7	0	3.3
	LTB 72.5-170D1/BGS				60	5.6	0	2.8
	HPL 72.5-300B1GS				50	0	6.7	3.3
	LTB 245E1GS				50	0	6.7	3.3
	HPL 72.5-300B1GS				60	0	5.6	2.8
	LTB 245E1GS				60	0	5.6	2.8
Opening	HPL 300B1/GS *)	Reactor	Y-0	5-leg/bank	50	0	6.7	3.3

US = Ungrounded bank, GS = Grounded bank

\*) Please note: For reactor deenergization, the reactor should be  $\geq 150$  Mvar at 300 kV.

For other applications with tree-pole operated mechanical staggered circuit breakers, please contact ABB Power Technologies, High Voltage Products, Ludvika, Sweden

# Technical Data for Switchsync™

Type of controller	E113 and E213	F236	L183	T183
Power supply Power consumption	110 - 250 V AC/DC < 4 VA	110 - 250 V AC/DC < 4 VA	110 - 250 V AC/DC < 4 VA	110 - 250 V AC/DC < 4 VA
Operating command Duration	48 - 250 V DC 0.15 - 2 s	48 - 250 V DC 0.15 - 2 s	48 - 250 V DC 0.15 - 2 s	48 - 250 V DC 0.15 - 2 s
Reference voltage detector Power consumption	35 - 150 V AC, 15 - 66 Hz < 0.1 VA	35 - 150 V AC, 15 - 66 Hz < 0.1 VA	35 - 150 V AC, 45 - 66 Hz < 0.1 VA	35 - 150 V AC, 15 - 66 Hz < 0.1 VA
Current start detector Short-time current Power consumption	0.5 - 5.0 A 100 A, 1 s 0.66 VA at 5.0 A	0.5 - 5.0 A 100 A, 1 s 0.66 VA/input at 5.0 A	-	-
Voltage start detector Power consumption AC DC	48 - 250 V AC/DC < 1.5 VA < 0.2 VA	48 - 250 V AC/DC < 1.5 VA/input < 0.2 VA/input	48 - 250 V DC - < 0.2 VA/input	48 - 250 V DC - < 0.2 VA/input
Trip information Power consumption	-	-	48 - 250 V DC < 0.2 VA	48 - 250 V DC < 0.2 VA
CB status detector Power consumption	-	-	48 - 250 V DC < 0.2 VA	48 - 250 V DC < 0.2 VA
Load voltage input Input impedance	-	-	55-70 or 100-120 V AC > 200 kΩ	55-70 or 100-120 V AC > 200 kΩ
Cross-section area of connecting leads	≤ 4 mm <sup>2</sup>	≤ 4 mm <sup>2</sup>	≤ 4 mm <sup>2</sup>	≤ 4 mm <sup>2</sup>
Socket screws	Hollow socket screws for easy plug-in connection of recording device during commissioning tests.			
Ambient temperature	-30 - +55 °C	-30 - +55 °C	-30 - +55 °C	-30 - +55 °C
<b>Immunity tests</b>				
Power interruption test	IEC 60255-11	IEC 61000-4-11 EN 61000-4-11	IEC 61000-4-11 EN 61000-4-11	IEC 61000-4-11 EN 61000-4-11
Power frequency withstand 2 kV, 1 min.	IEC 60255-5	IEC 60255-5	IEC 60255-5	IEC 60255-5
Surge/Transients	IEC 60255-4 Cl. III	IEC 61000-4-5 EN 61000-4-5	IEC 61000-4-5 EN 61000-4-5	IEC 61000-4-5 EN 61000-4-5
Burst/Fast transients	IEC 60255-22-4 Cl. IV EN 50082-2	IEC 61000-4-4 EN 61000-4-4	IEC 61000-4-4 EN 61000-4-4	IEC 61000-4-4 EN 61000-4-4
1 MHz burst transient	IEC 60255-22-1 Cl. III	IEC 60255-22-1 Cl. III	IEC 60255-22-1 Cl. III	IEC 60255-22-1 Cl. III
Electrostatic discharge	EN50082-2 (IEC 60801-2)	IEC 61000-4-2 EN 61000-4-2	IEC 61000-4-2 EN 61000-4-2	IEC 61000-4-2 EN 61000-4-2
Radiated electro-magnetic field	IEC 60801-3 (EN50082-2)	IEC 61000-4-3 EN 61000-4-3	IEC 61000-4-3 EN 61000-4-3	IEC 61000-4-3 EN 61000-4-3
Conducted radio frequency interference	EN 50081-2	EN 61000-4-6 IEC 61000-4-6	EN 61000-4-6 IEC 61000-4-6	EN 61000-4-6 IEC 61000-4-6
Vibrations	IEC 60068-2-29	IEC 60068-2-29	IEC 60068-2-29	IEC 60068-2-29
<b>Emission tests</b>				
Conducted and radiated emission	EN 50081-2	EN 55011A CISPR11A	EN 55011A CISPR11A	EN 55011A CISPR11A
Dimensions	146 x 146 x 298 mm	146 x 290 x 298 mm	146 x 290 x 298 mm	146 x 290 x 298 mm

# Shipping Data for Switchsync™

Type		E113 and E213	F236	L183	T183
Gross weight	kg	6.0	12.0	12.0	12.0
Net weight	kg	3.0	7.0	7.0	7.0
Dimension (box)	m	0.4 x 0.3 x 0.2	0.42 x 0.42 x 0.4	0.42 x 0.42 x 0.4	0.42 x 0.42 x 0.4
Volume	m <sup>3</sup>	0.024	0.071	0.071	0.071



Switchsync™ Controller E213



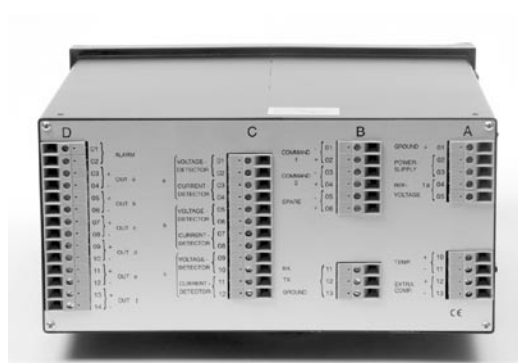
Switchsync™ Controller L183



Switchsync™ Controller T183



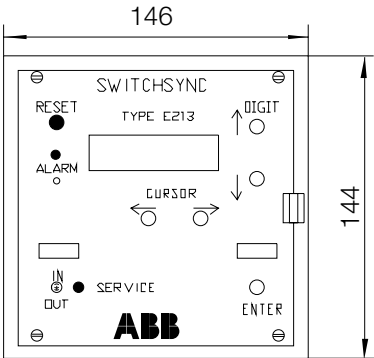
Switchsync™ Controller F236



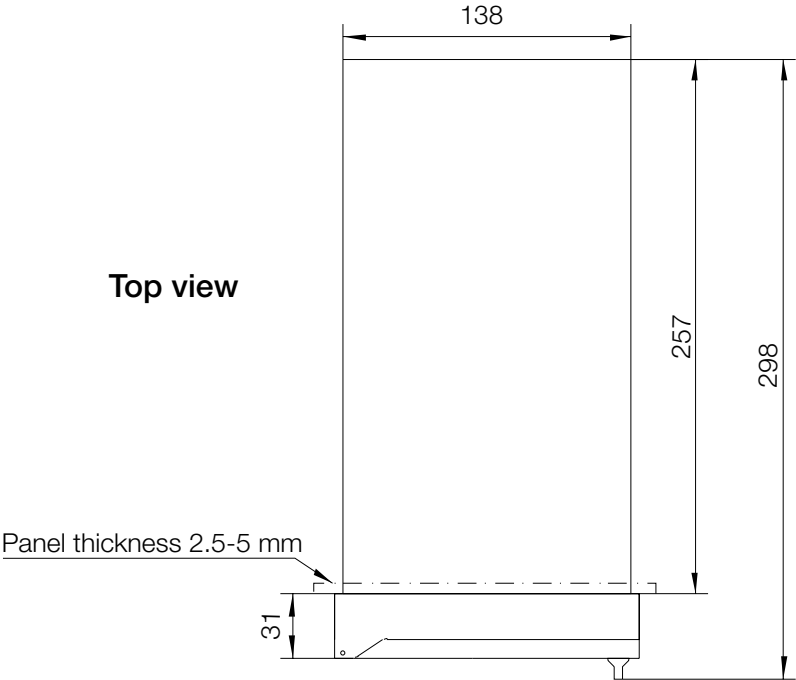
Rear view of Switchsync™ Controller F236

# Dimensions for Switchsync™ E113 and E213

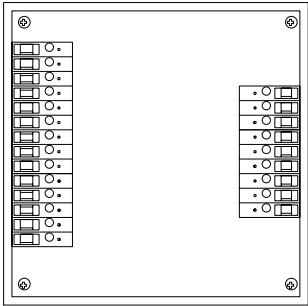
Front view



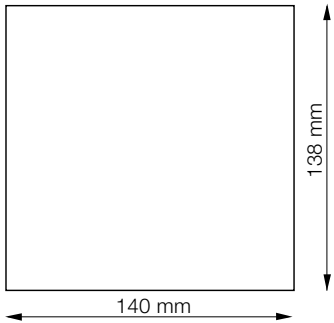
Top view



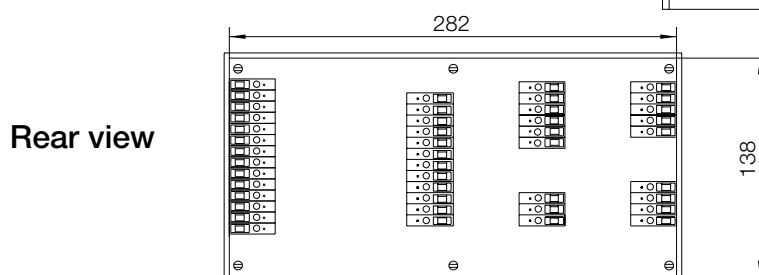
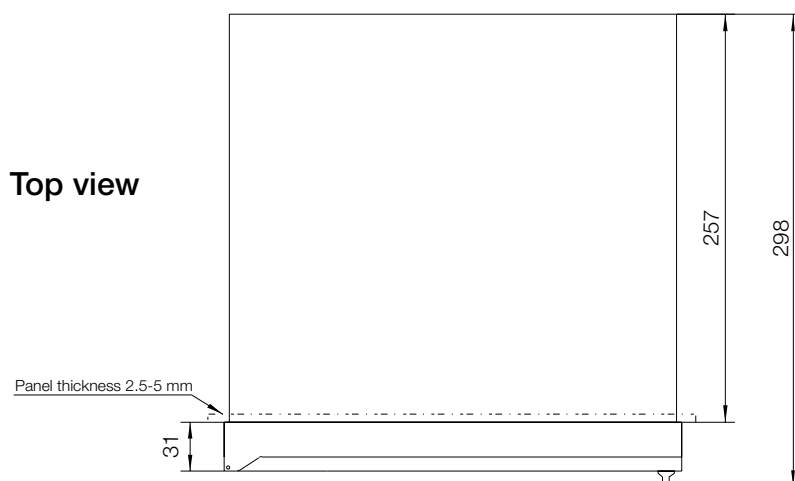
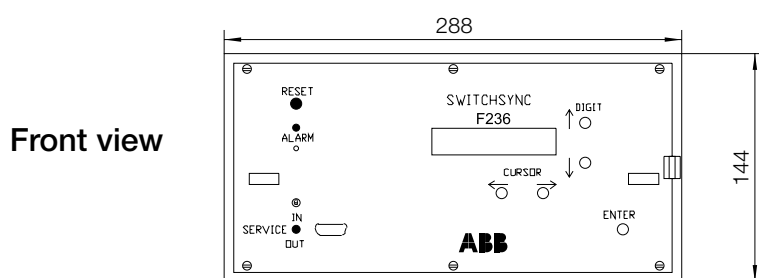
Rear view



Mounting Hole Dimensions



# Dimensions for Switchsync™ F236, L183 and T183



## Mounting Hole Dimensions



## Mounting



The side mounted "snap-on" counter screws shall be removed to allow for the controller to enter the hole in the panel.  
In final position the screws are easily snapped back and tightened.



## Accessories

The Switchsync™ controllers are stand-alone units providing full functionality for most normal applications. However, for increased user friendliness or for increased functionality for circuit breakers operated infrequently and under varying ambient conditions, the following additional accessories can be ordered:

### Communication Software for PCs

Communication software for PCs may be used for controllers F236, L183 and T183. The SWITCH2X software is delivered in a set consisting of a CD, an instruction manual and two cables. The connection between the PC and controller can be either via the modem port or directly to the RS 232 port on the controller front panel. The software facilitates programming and enables downloading of stored information on performed switching.

### Compensation Kit

When a circuit breaker design has a well-determined, functioning time dependency on external parameter variations (e.g. ambient temperature variation or auxiliary voltage variation) this can be handled by a compensation kit.

Such compensation kits can be used in combination with controllers F236, L183 and T183. The kits can be ordered complete with transducers, converters and cables.

Controllers F236, L183 and T183 can compensate for two external parameters that may affect the operating times, typically ambient temperature and auxiliary voltage.

### Precision Auxiliary Contacts

Precision auxiliary contacts may be used for adaptation control on contact touch. They are basically intended for controllers L183 and T183. These contacts should preferably be ordered in conjunction with ordering of the circuit breaker.

### Step-up Transformers

Step-up transformers for amplifying the secondary current are used for current start detection when the current will not exceed the minimum specified continuous value of 0.5 A. For controlled switching of three-pole operated circuit breakers, where only one secondary current is used for adaptation control, a prefabricated 19" plate can be ordered. This plate is complete with pre-assembled step-up transformer and hole for mounting the controller.

### Separate Pre-mounted 19" Rack Plate

For single-pole operated circuit breakers where individual adaptation for each pole is used, a separate pre-mounted 19" rack plate can be ordered. This is the case if the secondary current needs to be increased from a value below 0.5 A. This plate contains three step-up transformers and is designed for installation just underneath the plate that holds the controller.



Customer's  
Notes

# Quality, Testing and Commissioning

## Quality and Testing

Circuit breakers and controllers are type- and routine-tested according to applicable standards. The type tests are performed on representative units while each device produced is subjected to routine tests. Type- and routine tests are performed separately.

During routine testing, the controller functionality is tested under different conditions as shown in the table below.

Circuit breaker dummies are used in the tests to represent actual circuit breakers.

### The following checks are made during the routine tests:

Adjustments of detector circuits
Checking Watchdog and CRC-sum
Check of programming functionality on front panel
Check of closing and opening operations
Check of line side voltage measurements and residual flux measurements (L183 and T183 respectively)
Check of no operation while out of service
Check of behavior when reference voltage is lost
Check of behavior when multiple commands are received
Check of adaptation control by means of current start detection
Check of adaptation control by means of voltage onset detection
Check of performance in adaptive mode when adaptation control signal is lost
Functionality check of compensation circuits (F236, L183 and T183 only)
Check of behavior when supply voltage is lost
Check of performance when load side voltages are inaccessible (L183 and T183 only)
Check of rapid action
Check of operation without adaptation control
Check of operating properties when programmed for one mechanism only
Check of PC-communication properties (F236, L183 and T183 only)

As a final verification of the functional performance of the complete controlled switching system, it is advisable to follow the proposed test procedure for commissioning tests described in the next section.

## Commissioning

It is important to verify the overall functional performance of complete, controlled switching systems after installation.

The purpose of commissioning tests is to verify stable and intended results of the controlled operations.

For controlled switching operations that are performed in a non-adaptive mode, which is the case for most controlled opening applications, the controller makes no check of the results and tests are therefore needed to verify the performance. Additionally, controlled switching operations performed in adaptive mode must be verified upon commissioning to ensure that the intended results are attained. Even in adaptive mode, the controller may, because of incorrect settings or connections, display successful results even though this may not be the case.

The recommended commissioning procedures for different applications are given below.

### Switchsync™ E113, E213 and F236

For controlled switching applications when using Switchsync™ controllers E113, E213 and F236 (switching towards fixed targets) the following should be recorded:

- Busbar voltages (or at least the reference voltage)
- Load currents in each phase
- Output command(s) from the controller

The measured making instants can easily be compared to the intended making targets that are expressed as a certain phase shift with respect to the busbar reference voltage. For controlled opening, the output activation instants are needed to check the contact parting instants with respect to the phase shift of the load currents. The output commands together with the measured no-load opening times are used for the determination of contact separation instants. For operations performed in adaptive mode, read the display after each operation and cross check the displayed times against the recorded switching times.

# Commissioning

## Switchsync™ L183

For line switching applications using Switchsync™ controller L183, a different verification procedure is needed. Verification of the function under actual intended operating conditions - fault tripping followed by a reclosing operation - is not feasible. As a substitute, however, it is normally possible to arrange manual tripping of the line under no-load conditions, followed by a reclosing operation.

A simplified commissioning procedure should include control of the energizing instants for the three poles with respect to the phase angle of the source side voltages, and based on the measured trapped voltages.

The following should be recorded:

- Busbar voltages (or at least the reference voltage)
- Line current in each phase
- Output commands from the controller
- Functioning times of precision auxiliary contacts (if adaptation control is used)

After each switching operation, the display information should be noted and the energizing instants checked with respect to the measured trapped voltages. Guidelines for determination of appropriate energizing instants, dependent on the measured trapped charge, are given in the product manual. In addition, the signals from the auxiliary contacts can be used to verify that realistic pre-arcing times are reached.

Upon commissioning, the controller also makes a self-check of the polarity of its connections. It will give an alarm if the recorded busbar voltage and load side voltage are different when the circuit breaker is closed.

## Switchsync™ T183

To verify performance, the following should be recorded:

- Busbar voltages (or at least the reference voltage)
- Current in each phase
- Output commands from controller
- Functioning times of precision auxiliary contacts (if adaptation control is used)

The best way to verify the controlled switching function is to record the actual inrush currents during a few test operations. Limited amplitude and good symmetry of the currents are indications of proper function.

The energizing instants cannot be checked from the inrush current recordings, due to the non-sinusoidal wave-shape. In order to check the energizing instants, the load side voltages must also be recorded. However, for transformers with magnetically dependent phases, only the energizing instant for the first energized phase can be determined.

After each switching operation, the display information should be noted. Displayed closing times should be compared to recorded closing times.

Upon commissioning, the controller also makes a self-check of the polarity of its connections. It will give an alarm if the recorded busbar voltage and load side voltage are different when the circuit breaker is closed.

## General

Switchsync™ controllers are maintenance-free. After successful commissioning tests, there is no need for any further periodic checks of function, provided that operations are performed in adaptive mode. For applications in which no adaptive function is used, it is advisable to occasionally record a few operations after some years in service.

# Inquiry Data for Switchsync™ Controller

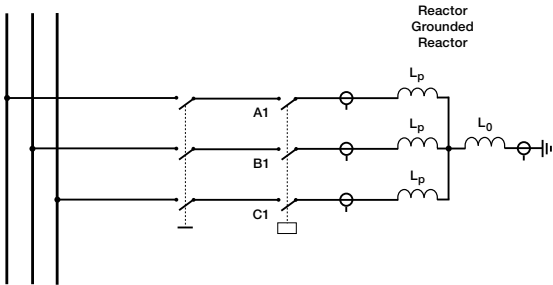
The following minimum information is required. Please send a filled-in copy along with your inquiry.  
For the circuit breaker(s) used together with the Switchsync™, please fill in "Inquiry Data for Live Tank Circuit Breakers" found in Buyer's Guide, Live Tank Circuit Breakers.

PROJECT DATA	
Customer / End customer	
Name of project	
Number of controlled circuit breakers	
Delivery time	

SYSTEM PARAMETERS ETC.	
Rated voltage (kV)	
Rated frequency (Hz)	
Substation configuration (E.g. double busbar, circuit breaker and a half etc)	
Available control voltage (V)	
Available ref. voltage from voltage transformer (V)	
Available voltage start signal (V) or current start signal (A). (For adaptive purposes) VT or CT ratio	
Ambient temperature (max. - min.) (°C)	

For further circuit breaker data, see Buyers Guide for Live Tank Circuit Breakers , Inquiry Data etc. ...

## Designation of inductances in case of reactor grounded reactor



$L_0$  in relation to  $L_p$  must be known if a three-pole operated circuit breaker is chosen. This is to ensure delivery of the correct type of circuit breaker.

## Acceptable combinations of power transformer winding types and VT types for T183

VT-type		Power transformer winding type
Y-0	Connected to	Y-0/without tertiary winding
Y-0, Y-N, D or V	Connected to	Y-0/D or Y1-N/D
		Z1-0/D or Z1-N/D
		Z11-0/D or Z11-N/D
		D1 or D11
1-ph	Connected to	1-ph

- Y-0: Y-connected grounded neutral
- Y-N: Y-connected isolated neutral
- D: Delta coupled
- V: V-coupled (measurement of two voltages)
- 1-ph: Single phase to ground

## Inquiry Data for Switchsync™ Controller

The following minimum information is required. Please send a filled-in copy along with your inquiry.

APPLICATION: Switching of Capacitor Banks and Harmonic Filters	
Number of circuit breakers	
Controlled closing	
Controlled opening	
Controlled closing and opening	
Size of capacitor bank (Mvar)	
Grounded neutral	
Ungrounded neutral or Delta	
Three-pole or single-pole operation	

APPLICATION: Switching of Shunt Reactors	
Number of circuit breakers	
Controlled closing	
Controlled opening	
Controlled closing and opening	
Size of reactor (Mvar)	
1- or 3-phase reactor (3 or 5 legs)	
- Grounded neutral	
- Ungrounded neutral	
Reactor grounded (Ratio of $L_p / L_o$ ) (See page O-1)	
Three-pole or single-pole operation	

APPLICATION: Switching of No-load Power Transformers	
Number of circuit breakers	
Controlled closing (residual flux disregarded or not)	
Controlled closing and opening	
Power transformer winding type (See page O-1)	
Load side VT arrangement (See page O-1)	
Three-pole or single-pole operation	

APPLICATION: Switching of Transmission Lines	
Number of circuit breakers	
Controlled closing	
Shunt-compensated lines	
Un-compensated lines	
Single-pole operation	



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NOTE: ABB Power Technologies AB is working continuously to improve the products. We therefore reserve the right to change designs, dimensions and data without prior notice.