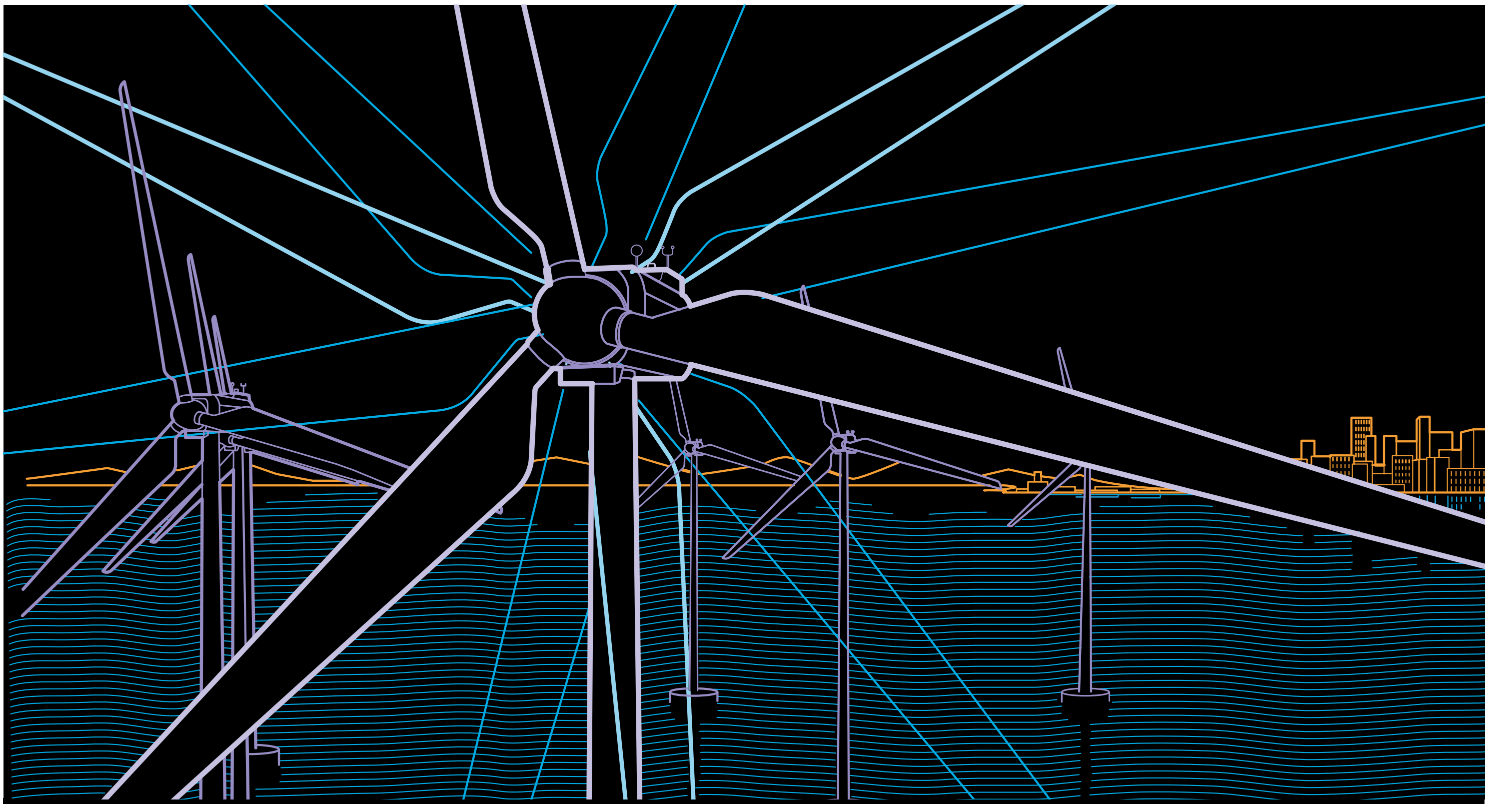


White paper

ABB solutions for switching and protection of low speed wind turbines

Power and productivity
for a better world™

ABB solutions for switching and protection of low speed wind turbines

Index

1. Introduction

Variable frequency is today widely used in application such as:

- wind turbine
- mini-hydroelectric
- wave
- traction.

In particular, in recent wind turbine designs, generators with Full Power Converter (FPC) are often employed instead of Doubly Fed Induction Generators (DFIG). In the FPC scheme, the generator (typically a PM machine) produces variable frequency currents and voltages, which are fed to a frequency converter capable of handling the full power flow. Then the converter feeds power at the network frequency to the downstream circuit.

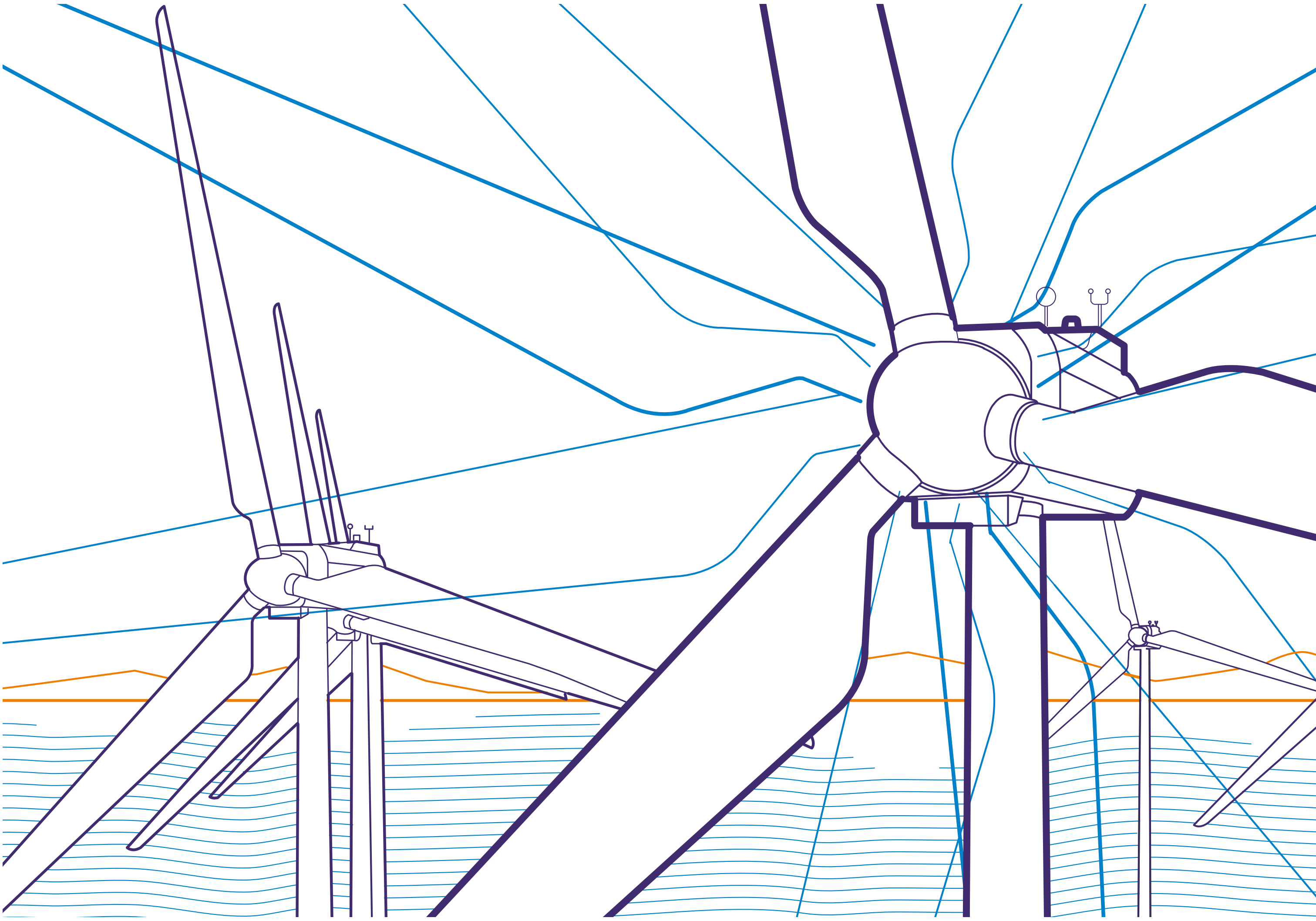
Besides choosing suitable switching and disconnection devices which can withstand the frequent operations and harsh environmental conditions, when designing a wind power plant it is also necessary to provide for the protection of the different sections of the plant against overcurrents and earth faults and surge due to lightning.

Protection against fault, which is a basic requirement of any electrical installation, is especially critical for wind generators, where faults can have catastrophic effects.

However, proper fault detection and clearance in PFC generators pose several new technical challenges to the designers of protection systems, e.g.:

- short circuit currents may be limited by the presence of power electronic devices, hence they may go undetected by conventional protection relays;
- fault currents in the part of the circuit upstream the converter have a variable frequency, so current sensors used to detect faults may not work as expected;
- a considerable short circuit power is fed by a variable-frequency source: interruption of the current may not be possible with conventional circuit breakers;
- voltage wave in the part of the circuit upstream the converter has a specific form including high peak voltages: use of conventional surge protective devices may lead to a fast damage of these devices.

Environmental stresses, both mechanical and climatic, have to



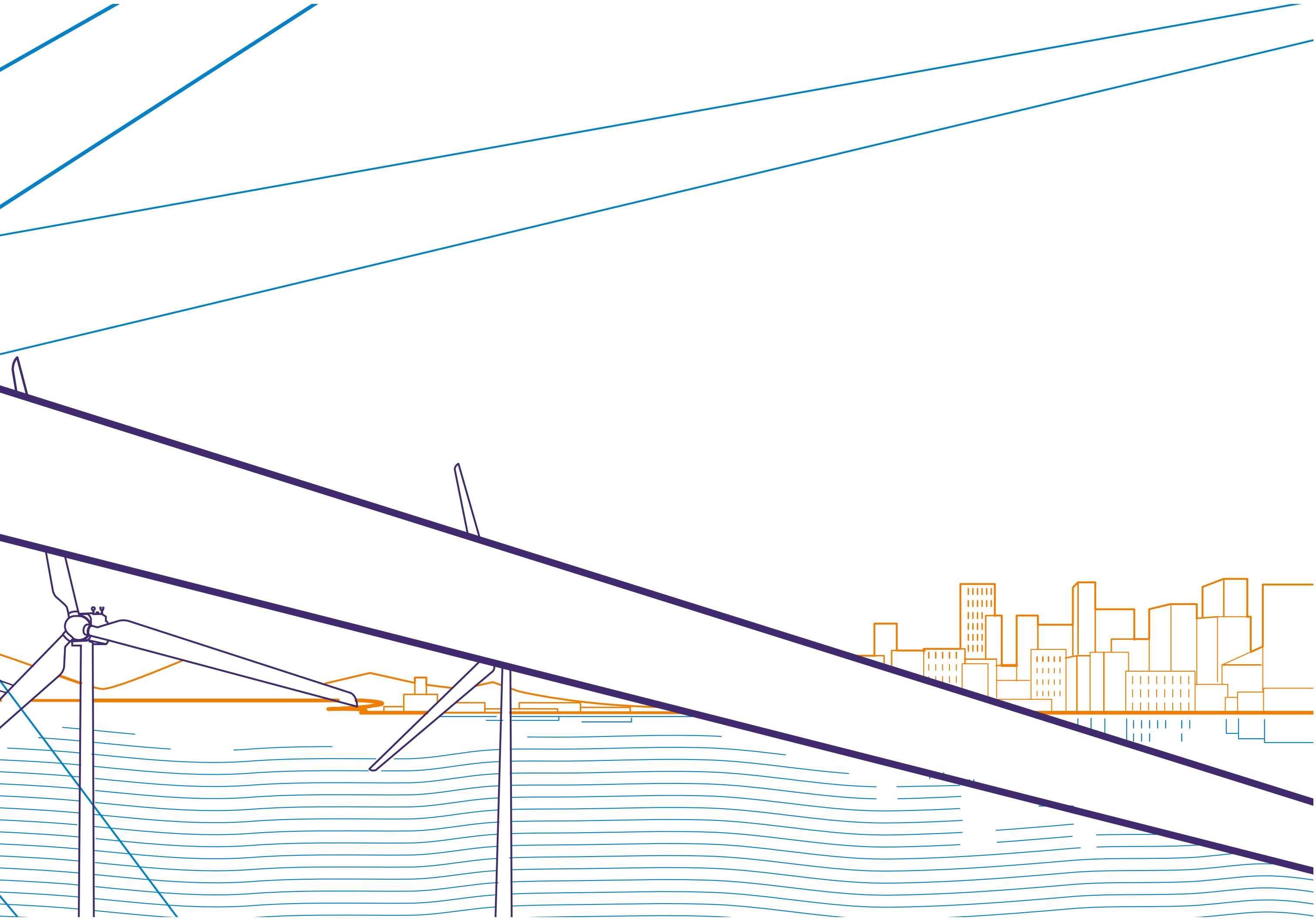
be considered as well. In the nacelle, low frequency vibrations are common, causing displacements, while the temperature may vary between -25°C and +50°C. In addition, humidity, dust and pollution are common problems.

All these factors cause a decrease in the equipment performance, and the life expectancy of low voltage components may be reduced up to 50%, compared to what could be achieved under ideal conditions. To guarantee reliable operation it is necessary to select the components according to their main function and with a wider safety margin.

The wish to minimize size and weight due to the physical constraints in the nacelle is at the same time in conflict with the demand for high efficiency and service continuity. Trying to merge different functions into a single component and pushing its performances to the limit often leads to the detriment of its reliability in the medium and long term.
Typical compromises of this kind are for instance the choice of circuit-breakers in the fixed version, which are less easy to be maintained, but offer smaller overall dimensions than the corresponding withdrawable version or making the protection element (circuit-breaker) also perform the power control functions usually carried out by a contactor.

To summarize, in addition to preventing and limiting faults, the protection and control system shall be dimensioned and coordinated so that the effects of the electrical transients on the mechanical system – which accounts for around 80% of the turbine cost – can be avoided.

To achieve this result, the key points are, in order of importance:
- high switching reliability
- reduced maintenance
- minimized size and weight.



2. Full converter configuration

A typical power circuit of full converter configuration is shown in Figure 1. On the grid side of the converter, “contactorless” designs are also possible, in which the circuit-breaker is used for both switching and protection.

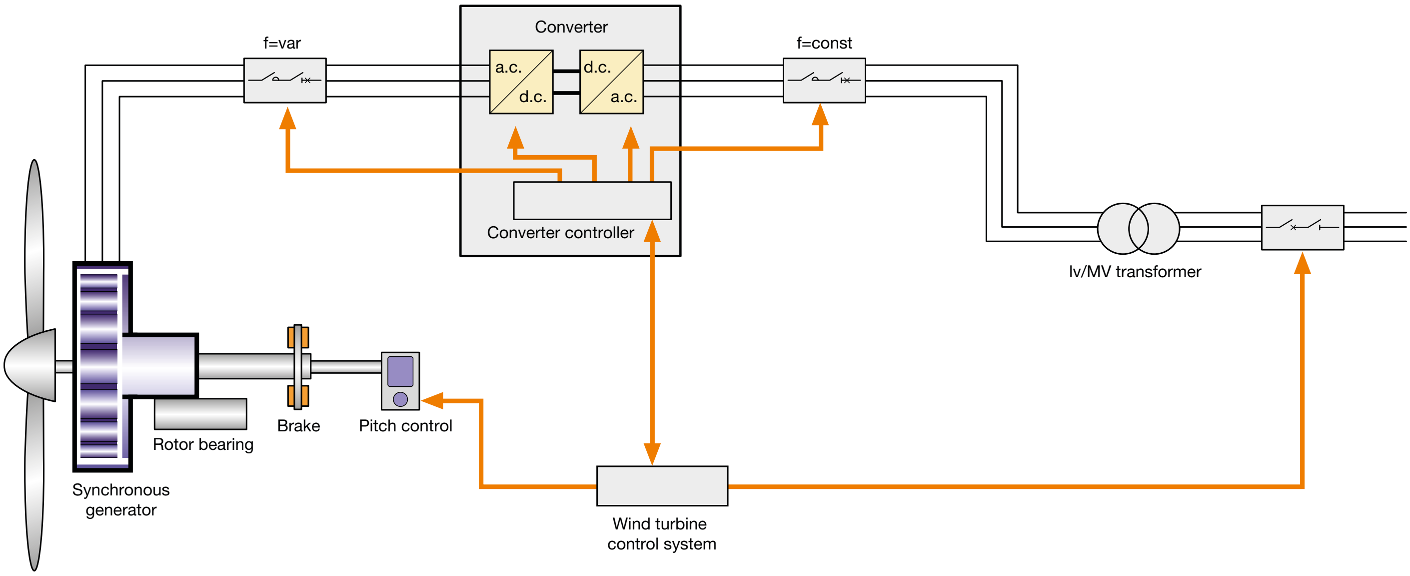
However, employing a contactor for switching operation, coordinated with a circuit-breaker for protection and disconnection, is usually considered a better solution, providing a much higher overall reliability.

The circuit-breaker positioned between generator and converter must be able to operate at a variable frequency (typically ranging from 1 to 200 Hz according to the rotation speed of the alternator) and must carry out the following functions:

- isolation: during normal operating or maintenance cycles, the disconnection devices are controlled by the automatic inverter system. In this application, safe isolation is necessary to ensure that the source, represented by the generator, is isolated from the remaining part of the circuit, since semi conductor devices must not be used alone as isolation devices (IEC 61400-1);

- back-up: certification bodies require that, during a fault, a redundancy for the protection system inside the inverter is present, which acts on the generator disconnection: the circuit-breaker is, as such, an effective back-up system;

Figure 1



- protection: in the event of a fault involving the inverter or of a fault in the section between the generator and the inverter (e.g. in the cable connection), the circuit-breaker is the device that is able to detect the fault and trip by disconnecting the source and protecting the cable. The likelihood of a fault is fairly high, especially when the cable length is considerable, e.g. when the converter is installed at the base of the tower (Figure 2).

Table 1 summarizes the main characteristics to take into consideration when selecting circuit-breakers and contactors for the main power circuit on the generator side and grid side and for the main auxiliary circuit.

Figure 2

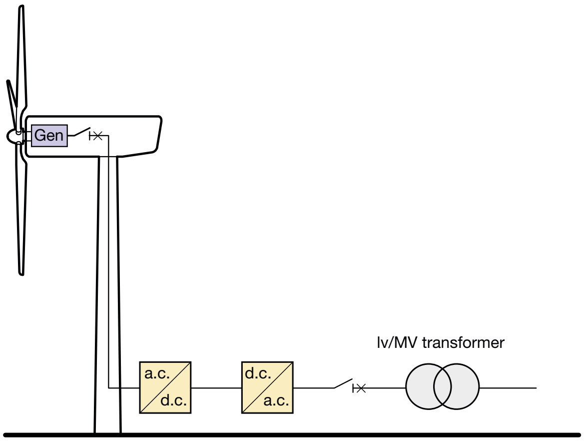


Table 1

Characteristics	Main power circuit on the generator side	Main power circuit on the grid side	Main auxiliary circuit
Load current [A]	≤ 5000 or nx 700…1600	≤ 5000 or nx 700…1600	< 250
Voltage [V]	≤ 1000	≤ 690	≤ 690
Frequency [Hz]	1…16	50 - 60	50 - 60
	30…80		
	40…140		
Prospective-short circuit current [kA]	≤ 15 @ 1000V*	35 @ 690V	
Presence of inrush current	No	No	Yes
Type of load	AC1	AC1	AC3
Life time [years]	20	20	20
Number of mechanical operations (or electrical operations at low current) to disconnect the system (maintenance or out of service)	100…1000	< 1000	< 1000
Number of mechanical operations (or electrical operations at low current) of connection to/disconnection from the grid or of reconfiguration (production control)	Not available (generally the generator remains connected to the converter)	1000…100000 (according to the control strategy)	Not applicable
Number of electrical operations	< 500 (tripping of protections or emergency stop)	< 500 (tripping of protections or emergency stop)	> 500 (tripping of protections or emergency stop)
Protection against overcurrents	Yes	Yes	Yes
Optimum solution	Circuit-breaker (if protection is required for the connection cable or the inverter input)	Circuit-breaker + contactor more than one operation per day required)	Circuit-breaker
	Switch-disconnector (if an external protection system is present)	circuit-breaker (less than one operation per day)	

2. Full converter configuration

As regards the protection against lightning surges and overvoltages with this configuration of wind converter, it is recommended (Figure 3) to place an SPD Type I in the main switchboard at the entrance of the turbine for the protection against transient overvoltages of atmospheric origin and against the surge current from the network. If the SPD Type I does not have an effective protection level (Up) lower than the maximum withstand voltage of the devices to be protected (Uw) or the distance from the devices to be protected is longer than 10m, it is recommended to install an SPD Type II near the converter on the grid side for a better protection.
It is also recommended to install between the converter and the synchronous generator some SPDs Type II suitable for protection in the presence of transient overvoltages superimposed on the PWM (Pulse With Modulation) control voltage.

Actual variable speed wind turbines are equipped with PWM controlled converters using IGBT or IGCT in order to regulate their output voltage and frequency.
These technologies, if not filtered properly, generate peak transient overvoltages superimposed on the PWM control voltage (as shown in Figure 4).

These peaks, of several kV, will be seen by a standard SPD as transient overvoltages due to lightning, creating unwanted triggering of the surge arresters with a high frequency and therefore reducing considerably their life time. That's why it is safer to use specific SPDs having Urp (peak repetitive voltage withstand characteristics) higher than the above mentioned peak transient overvoltages.

Figure 4

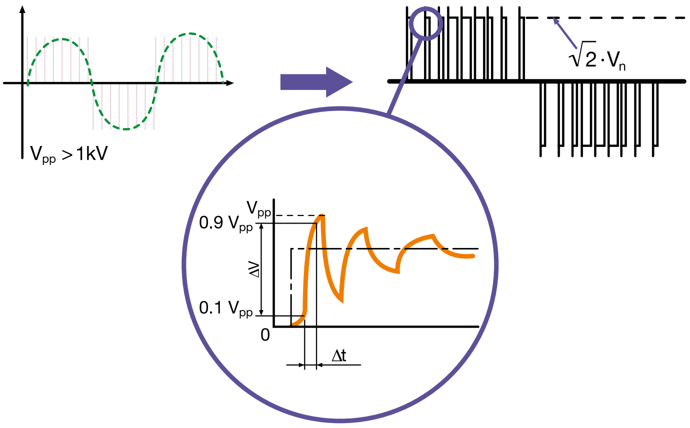
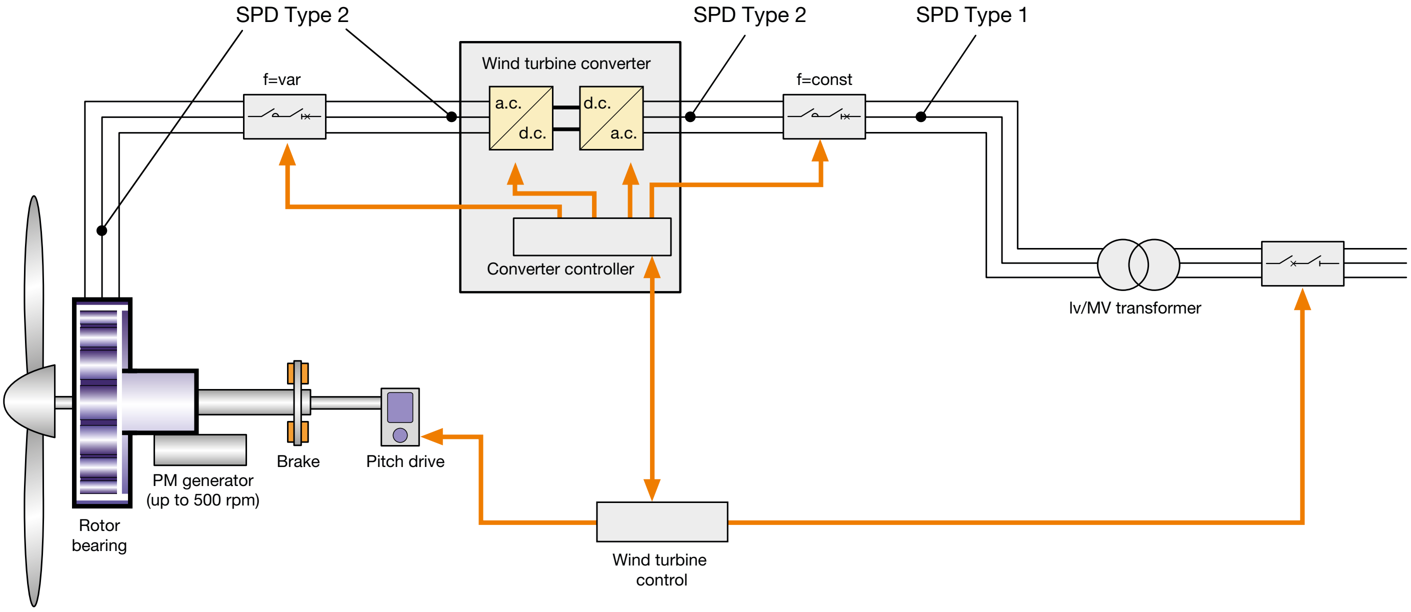


Figure 3



3. SACE VFT

3.1 Generalities

The new ABB SACE circuit-breakers for variable frequency (Figure 5) integrate advanced monitoring, protection and control functions thus reducing:

1. number of components installed (e.g. external trip unit and sensors)
2. space and wirings
3. engineering, installation and testing costs.

Figure 5

ABB SACE Emax VF for variable frequency, is not only perfectly suitable for variable frequency applications, providing a complete and fully-integrated solution for high level variable frequency applications, but is also unique: no other product on the market offers such characteristics.
The weak point of many installations is wiring. It costs time and money to wire a new item into the setup, and more time and money to test and verify it.

The answer lies in integration: combining as much functionality as possible into a single device.
Switch-disconnectors used in combination with external electronic trip unit can offer a range of standard protection functions but they cannot meet other very important requirements.

As they are not an integrated solution, the customer must install the trip unit and current sensors in the switchboard. This means that the dimensions of the switchboard cannot be as compact as they are in the case of a circuit breaker of this new series.

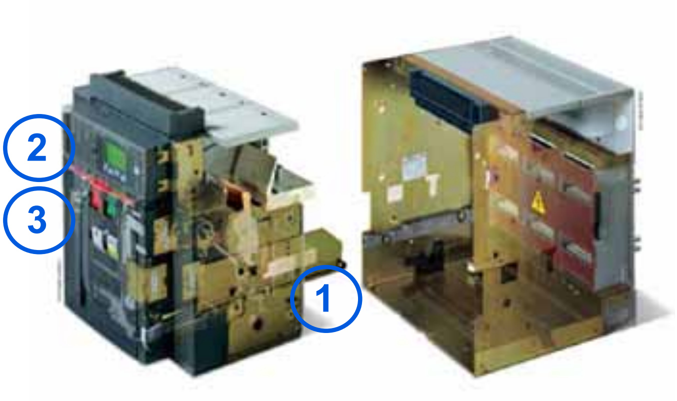
Furthermore, the need to connect, wire and test the external trip unit system implies additional engineering and installation costs.

3.2 New architecture

The system architecture of the new VF circuit-breaker (Figure 6) includes:

1. resistive current sensor for measurement and protection
2. electronic trip unit
3. actuator to open the circuit-breaker (trip coil).

Figure 6



3.2.1 Trip unit

The trip unit uses the same architecture as the present Emax AC series (Figure 7) with the possibility of adding modules (PR120/D-M and PR120/K).

Figure 7

New Software

The software has been modified to measure the current in a wide range of frequency (from 1Hz to 60Hz) and to adapt the protection algorithms to the new measuring method.

Signal conditioning

To guarantee the maximum measurement accuracy over a wide range of currents and frequencies by exploiting the maximum dynamics of the AD converter, the signals coming from different shunt sensors are scaled using an analogue circuit.

Supply stage

The supply stage controls the power coming from an external insulated supply source and delivers the energy to each part of the electronic system at the required voltage levels.

The hardware has been enhanced to meet the VF requirements for higher insulation and lower signal processing.

Processing unit

The signal from the shunts is amplified and adjusted to make it proportional to the CB rated current (In).

The electronic system is sensitive to low signals and it remains immune to high external disturbances and to short-circuit currents thanks to the choice of high-performance components and a very accurate PCB layout.

The processing unit is fully modular and developed according to the best software engineering practices and internal software quality procedures.

3.2.2 Shunt

The shunt is the current sensor. It provides a voltage signal proportional to the current. When designing the shunt, the challenge was to define a device compact enough to be installed inside the circuit-breaker.

The shunt has a resistance high enough to drive the electronics of the trip unit but low enough to permit power dissipation compatible with the plastic support of the circuit breaker, both at rated current and under short-circuit conditions.

To obtain the required functionality at the rated current, the shunt temperature has been kept as low as possible by increasing the thermal conductivity.

To ensure functionality under overcurrent conditions, the designers maximized the thermal time-constant of the shunts in order to increase their overload performance (i.e. to reduce the temperature rise of the shunt during overloading).

This has been achieved by optimizing the shape of the shunt-assembly, i.e. by increasing the mass without reducing the thermal conductivity.

3.2.3 Trip coil

The circuit breaker is opened by an electromagnetic actuator. This actuator is controlled by the electronic trip unit.

The main challenge was designing a small, cost-effective and high-performance actuator which, at the same time, was able to prevent the circuit breaker from unwanted tripping.

This was achieved by shielding it against the very high electromagnetic fields generated by the short-circuit currents flowing in the main bar.

The correct dimensioning of the actuator was achieved by means of a magnetic field FEM analysis.

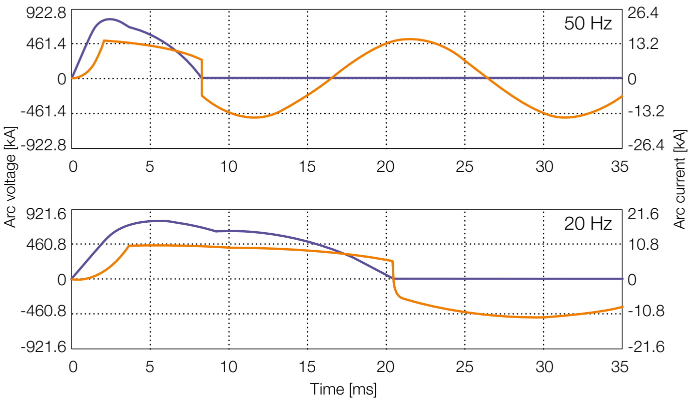
3.3 Performances at low frequencies

As Figure 8 shows, a voltage and current frequency lower than the common 50/60 Hz determines a longer period of these electric quantities, which involves higher arc energy. In fact, the integral [1] to calculate the arc energy is considered over a longer time interval:

$$E = \int_0^T v(t) \cdot i(t)dt$$

The higher arc energy developed during the breaking process at low frequencies causes a variation in the electrical life and in the current breaking capacity. In fact, as it can be noticed in the example of Figure 8, when passing from 50Hz to 20Hz there is a rise of the period of the voltage and current values: this implies that, by interrupting the arc on the first passage of the current through zero, the subtended area of each curve is greater and thus the product resulting by [1] increases. As a consequence, the associated arc energy and the interruption are more difficult.

Figure 8



3.4 Main characteristics

Table 3 – Circuit-breakers for low frequency applications

		T6 VF	E2 VF	E3 VF
Performance level		**L**	**N**	**H**
Number of poles		3	3	3
Operating Frequency	[Hz]	1...60	1...60	1...60
Version [Fixed (F), Drawout (W)]		F, W	F, W	F, W
Operating temperature	[°C]	-25...+70	-25...+70	-25...+70
Storage temperature	[°C]	-40...+70	-40...+70	-40...+70
Reference standards		IEC 60947-2 UL 489	IEC 60947-2 -	IEC 60947-2 -
Currents				
Rated uninterrupted current (at 50/60Hz, 40 °C) Iu	[A]	800(1)	1200 1600	2000 2500

IEC 60947-2 characteristics (at 10...60Hz)				
Rated service voltage **Ue**	[V]	1000	1150	1150
Rated insulation voltage **Ui**	[V]	1000	1250	1250
Rated impulse withstand voltage **Uimp**	[kV]	8	8	8
Rated ultimate short-circuit breaking capacity Icu				
690 V	[kA]	15	20	25
1000 V	[kA]	7.5	15	20
Rated service short-circuit breaking capacity Ics				
690 V	[kA]	10	20	25
1000 V	[kA]	3.75	15	20
Rated short-time withstand current **Icw** (1s)	[kA]	7.5	15	20
Rated service short-circuit making capacity (peak value) Icm				
690 V	[kA]	31.5	42	52.5
1000 V	[kA]	15.75	31.5	42
Utilisation category (in accordance with IEC 60947-2)		A	B	B
Insulation behavior (in accordance with IEC 60947-2)		■	■	■

UL 489 characteristics (at 10...60Hz)				
Rated voltage	[V]	600	-	-
Rated short-circuit current				
240 V	[kA]	15	-	-
480 V	[kA]	15	-	-
600 V	[kA]	15	-	-

Note: the breaking capacity Icu (at 1000V from 10Hz to 200Hz) by means of external protection relay, with 500 ms maximum timing, is equal to the value of Icw (1s). For frequency lower than 10Hx, please contact ABB SACE.

(1) Power supply only from the top.

3. SACE VFT

Table 4 – Switch-disconnectors for variable frequency applications

		T6D/VF	E2N/VF MS	E3H/VF MS	E4H/VF MS	E6H/VF MS
Number of poles		3	3	3	3	3
Operating frequency	[Hz]	1...200	1...200	1...200	1...200	1...200
Version [Fixed (F), Drawout (W)]		F, W	F, W	F, W	F, W	F, W
Operating temperature	[°C]	-25...+70	-25...+70	-25...+70	-25...+70	-25...+70
Storage temperature	[°C]	-40...+70	-40...+70	-40...+70	-40...+70	-40...+70
Reference standards		IEC 60947-3 -	IEC 60947-3 UL 1066	IEC 60947-3 UL 1066	IEC 60947-3 UL 1066	IEC 60947-3 UL 1066
Currents						
Rated uninterrupted current (at 50/60Hz, 40 °C) Iu	[A]	800(1)	1200 1600	2000 2500	3600	5000
IEC 60947-3 characteristics						
Rated service voltage **Ue**	[V]	1000	1150	1150	1150	1150
Rated insulation voltage **Ui**	[V]	1000	1250	1250	1250	1250
Rated impulse withstand voltage **Uimp**	[kV]	8	12	12	12	12
Rated short-time withstand current **Icw** (1s)	[kA]	7.5	15	20	25	25
Rated service short-circuit making capacity (peak value) Icm						
690 V	[kA]	31.5	42	52.5	63	63
1000 V	[kA]	15.75	31.5	42	52.5	52.5
UL 1066 characteristics						
Rated voltage	[V]	-	600	600	600	63
Rated short-circuit current	[kA]	-	20	25	30	52.5

Note: the breaking capacity Icu (at 1000V from 10Hz to 200Hz) by means of external protection relay, with 500 ms maximum timing, is equal to the value of Icw (1s). For frequency lower than 10Hz, please contact ABB SACE.

(1) Power supply only from the top.

4. Contactors

4.1 General

The function of a contactor is remote switching of the main circuits under normal operating conditions.
A contactor is a device designed for many switching cycles and therefore it is complementary to breakers.
The requirements and dimensioning of a contactor depend also on whether the switching is carried out with or without a load.
When switching under load, the electrical life of the contactor can be one of the dimensioning factors; when switching without load, the mechanical life can be applied.
The contactor control is provided by a separate control circuit, which is normally not affected by variable frequency.

4.2 Performances at low frequencies

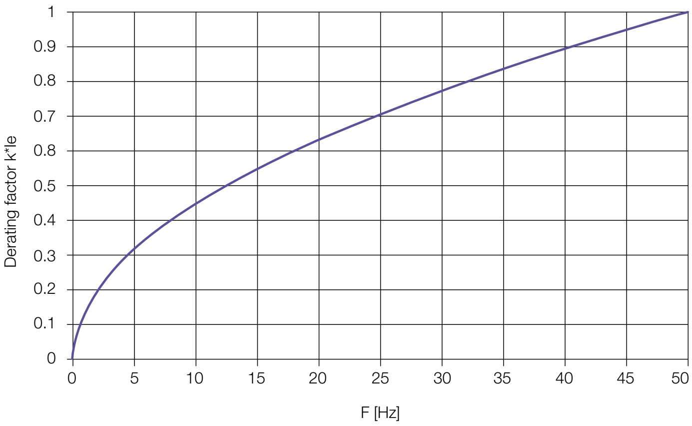
The same basic theory as described in 3.3 also applies to contactors. Longer arcing time means increased wear of the contact material when breaking (opening contactor).

The most important factor for contact wear is the current, which is related to the lifetime of the main contact. In low variable frequency applications (where the current is constant the factors in Figure 9 are to be applied to maintain the electrical life stated in the catalogue).

By applying the derating factor, the contactor selection can be done according to normal procedure.

Figure 9

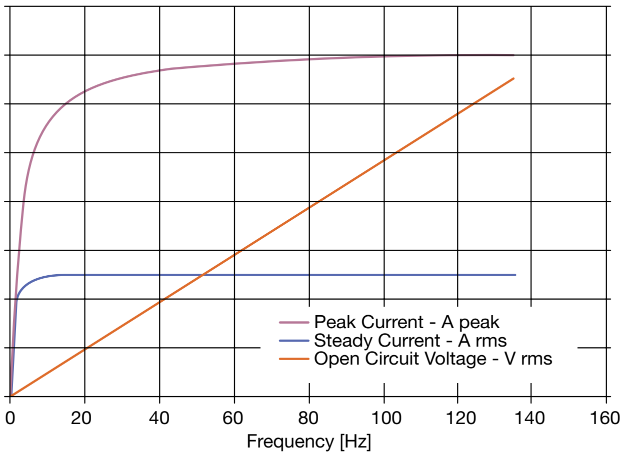
Derating factor k for Ie AC-1 at low frequency [f]



4.2.1 Wind application, full converter solutions

Normally, the current is zero or very low when switching (Figure 10). Therefore, contact wear, even at low frequencies, is less than catalogue data.
Thanks to the very low current at switching in this application, the mechanical life value is applicable.
Therefore, in this particular application, no derating factor is needed and the selection of contactors can be done according to the standard contactor data.

Figure 10



5. ABB OVR WT

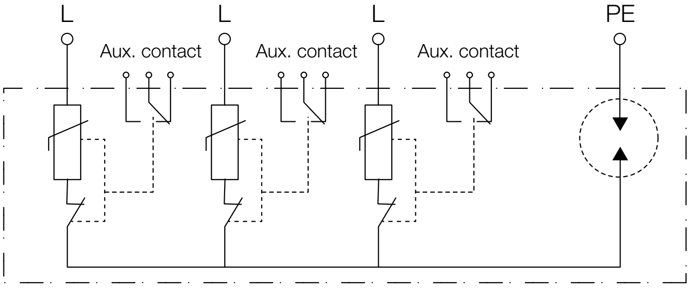
5.1 Main features

The low voltage surge protective devices (SPD) from ABB Soule OVR WT 40 690 P TS (Figure 11) have been specially designed for variable frequency applications up to 1000VAC.

A combination of a high surge capacity metal oxide varistor (MOV) in series with a spark gap (as shown in Figure 12) offers this specific SPD the possibility to combine high surge protection capacity with an Iimp=2.5A 10/350 and Imax=40kA 8/20 per pole and high withstand of the repetitive peak voltages created by this application (up to 3kV phase to ground and 3.4kV line-to-line).

Figure 11

Figure 12



5.2 Additional features

5.2.1 Cartridge lock

Cartridge locks (Figure 13) ensure correct positioning of the plug-in part of the SPD. Thus, it is possible to avoid unwanted unplugging of the cartridges due to the vibration induced by the application, especially when the SPD is installed on the turbine generator itself.

Figure 13

5.2.2 Pluggability

The pluggable feature of ABB surge protective device as illustrated in Figure 14 facilitates maintenance.

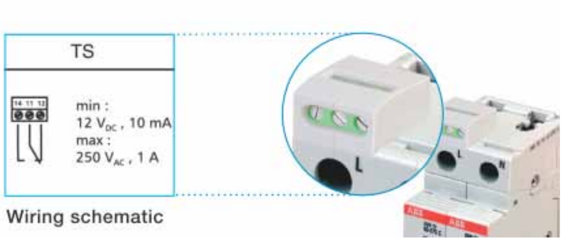
Should one or more worn cartridges need to be replaced, the electrical circuit does not have to be isolated nor do the wires have to be removed, thus ensuring a fast and safe maintenance.

Figure 14

5.2.3 Remote contact

This function (Figure 15), achieved by wiring a 3-point 1a volt-free contact, enables the operational state of the surge protective device to be checked remotely (maintenance station), thus increasing safety of system and reducing maintenance costs.

Figure 15



5.3 Back-up protection

Surge protective devices must have internal and external disconnectors. Internal is the so called thermal disconnection which helps to disconnect the SPD at the end of life (varistor technology) and is built-in in the SPD itself. External is the back-up protection, which, in this application, can be a MCCB or a fuse dedicated to the SPD protection in case of short-circuit due – for example – to very high surge transient current.

Considering the possible short-circuit current which can be due to the variable frequency power source, a Tmax VF or DC fuses with In < 125A are recommended as back-up protection of the OVR WT 3L 40 690 P TS.

5.4 Main characteristics

Electrical chararacteristics		
Types of networks		TNC/IT
Number of poles/Type of current		3/AC
Type/test class		T1 - T2/I - II
Nominal voltage Un (L-L)	V	690
Withstand Repetitive Peak voltage Urp (L-PE/L-L)	V	3000/3400
Maximal continuous operating voltage Uc (L-PE/L-L)	V	1260/2520
Voltage protection level Ures at 3 kA (L-PE)	kV	< 4.4
Voltage protection level Ures at 5 kA (L-PE)	kV	< 4.7
Voltage protection level Ures at 10 kA (L-PE)	kV	< 5.3
Voltage protection level Up at In (L-PE)	kV	< 6
Nominal discharge current Imax (8/20)	kA	20
Maximal discharge current Imax (8/20)	kA	40
Maximal discharge current Iimp (10/350)	kA	2
Follow current If	A	none
Response time	ns	< 100
Operating current Ic	mA	< 0.1
Short-circuit withstand Icc at Un	kA	50
Integrated thermal disconnector		Yes
State indicator		Yes
TS remote indicator		Yes

Contact us

ABB SACE
A division of ABB S.p.A.
L.V. Breakers
Via Baioni, 35
24123 Bergamo - Italy
Tel.: +39 035 395 111
Fax: +39 035 395306-433
www.abb.com

1SDC007411G0201 - 06/2013

Power and productivity
for a better world™