Wind turbine application

How to select coordinated main circuit breakers and TeSys F contactors

Application note

Technical collection

Schneider Electric

Introduction

Wind turbines are a very demanding application for embedded equipment including switchgear.

- Severe environmental stresses including temperature variation, humidity, wide spectrum vibration
- Potential unusual electrical phenomena (voltage and frequency variations, transient currents, high frequency component due to converters, etc.)
- Reduced avaible room for installation
- No staff on site during operation, so high reliability is required.

Meanwhile, technologies are changing from constant speed induction generators to direct drive with full conversion via doubly-fed induction generators and increased unit power.

As a consequence it can be challenging to select electrical equipment in general and power circuit breakers and contactors in particular. This document aims to provide recommendations for selecting and operating switchgear in association with the dedicated Tesys F range of contactors in wind turbines.

Overview of wind turbine principles in the 0.6 MW – 3 MW range

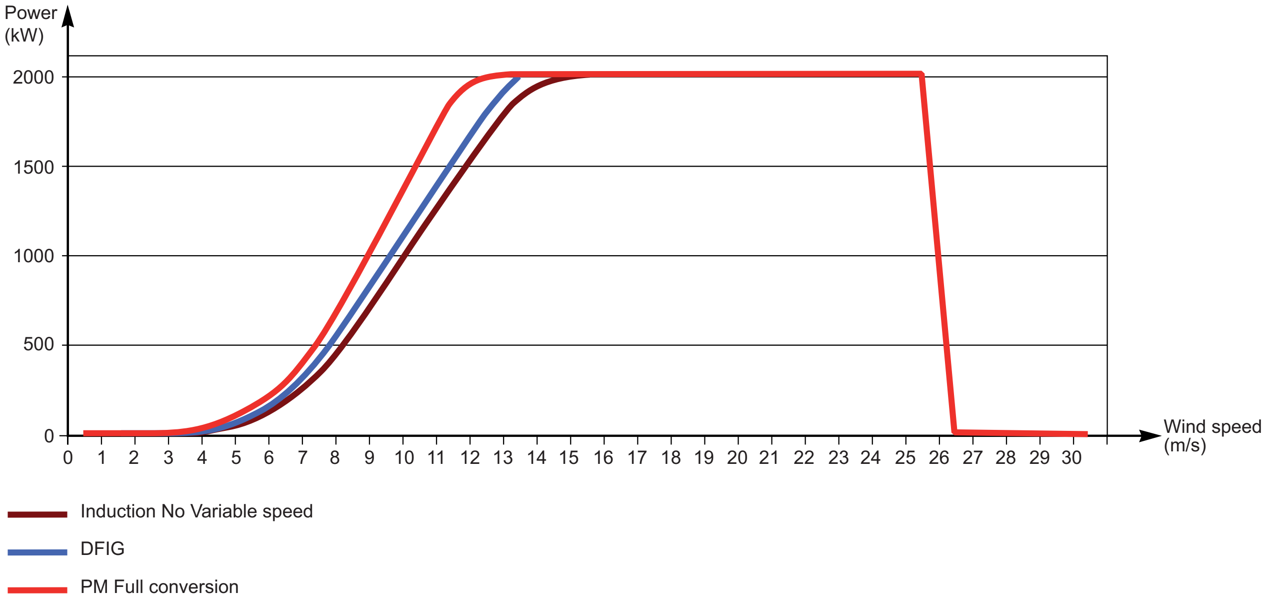
This chapter describes the main principles of mechanical to electrical power conversion in wind turbines in order to introduce electrical single line diagrams and switchgear needs. In the power range considered, the rotor speed is very often variable, and in that case a frequency converter is necessary.

Wind turbine mechanical to electrical power conversion may be divided into three subcategories:

- Wind turbine direct grid connection (induction generator)
- Wind turbine with indirect grid connection and gearbox (synchronous or induction generator)
- Wind turbine with indirect grid connection without gearbox (synchronous generator)

The main purpose of variable speed is to reduce the stress on mechanical parts (rotor, gearbox, bearings, etc.) and to improve the efficiency, notably at low speed.

Example of power curve for different designs



These different principles will have a major impact on the selection of LV switchgears.

Wind turbine with direct grid connection (induction generator)

Constant speed induction generator

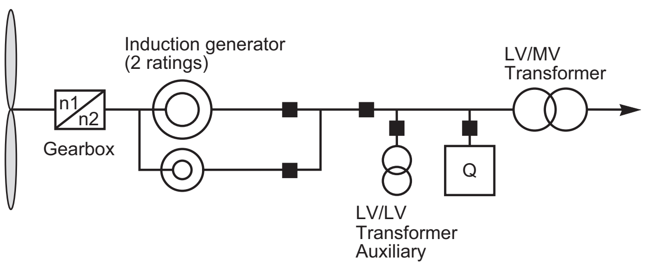
Like for induction motors, various designs have been used in wind turbines based on induction generators including double rating generators, Star Delta connection, soft starter, rotor slip control, etc.

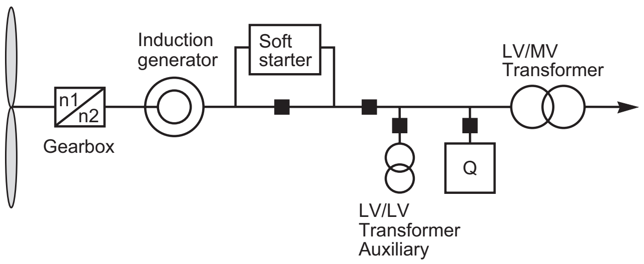
Usually these designs are used for wind turbines of less than 1 MW.

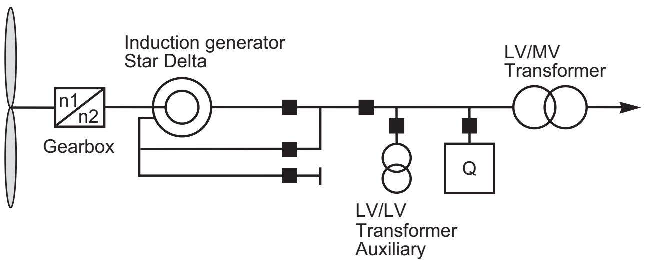
Above 600 kW, rated voltage is usually 690 V (or 575 V for UL design) 50/60Hz.

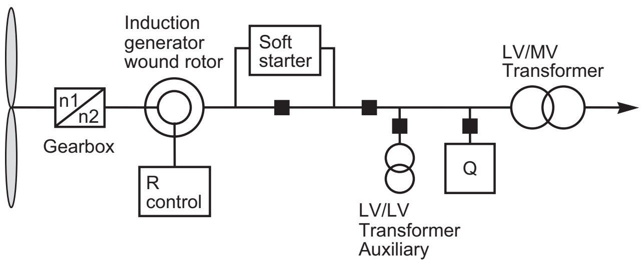
The existing offer of contactors and circuit breakers can be used in these designs.

As the induction generator is directly connected to the grid, at least one contactor is necessary to ensure connection and disconnection.









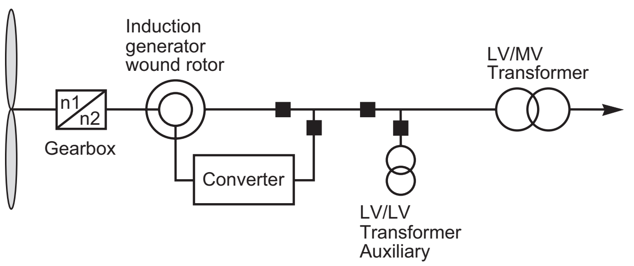
Doubly-Fed Induction Generator (DFIG)

From 1 MW to 3 MW, the Doubly-Fed Induction Generator is a very common design.

Rotor fed by converter allows variable speed and separate active/reactive power control.

Rated voltage is usually 690 V 50/60 Hz.

As the induction generator is directly connected to the grid, a contactor is necessary to ensure connection and disconnection (Number of operations can be up to 25 per day).



■ = Protection and/or control gear

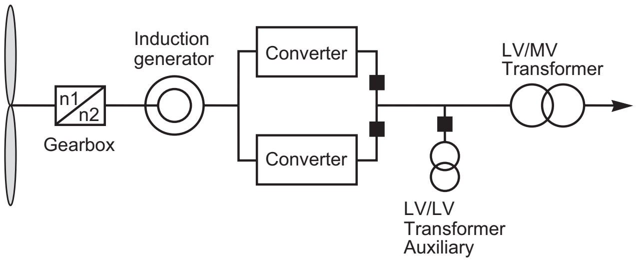
Wind turbine with indirect grid connection with gearbox

In order to increase variable speed capability, some wind turbine manufacturers propose a design with full conversion between generator and grid. This design offers better behavior regarding wind burst and grid disturbance, with less mechanical stress for mechanical parts, less noise and a slight improvement in the power curve.

Usually the power is increased by adding several converters in parallel.

Full conversion induction generator

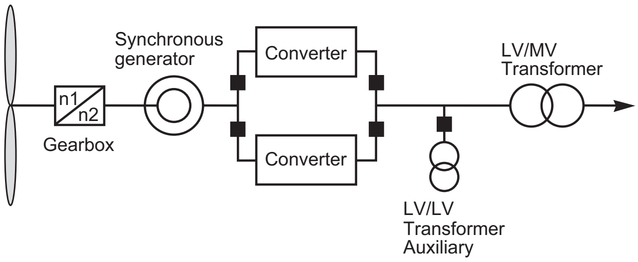
In this design no protection or control device is required between generator and converter.



Full conversion synchronous generator

In this design a protection device is required between generator and converter. Frequency and voltage are variable. ~ 15 Hz – 150 Hz. Maximum voltage is usually 690V but could be higher (up to 900 V).

Synchronous generator could use permanent magnet or external excitation.



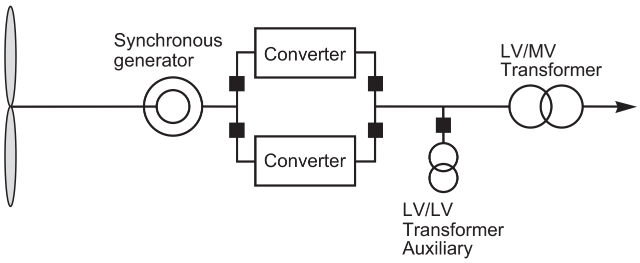
Wind turbine with indirect grid connection without gearbox

This scheme is comparable to the previous ones except that there is no gearbox which is a source of difficulty in wind turbines. This scheme leads to a multi-pole generator with a much larger diameter than previous ones, so the nacelle shape is very different.

Full conversion synchronous generator without gearbox

In this design, a protection device is required between generator and converter. Frequency and voltage are variable.
Frequency between ~ 5 Hz – 20 Hz .
Maximum voltage could be up to 900 V.

Synchronous generator could use permanent magnet or external excitation.



Selection guide for main LV switchgear

In this document we will focus on DFIG design and full conversion designs. Direct connection of induction generators without rotor control by a converter is normally used for rated powers < 1 MW and creates no major challenge for switchgear selection.

DFIG Design

General

Three different designs of DFIG are described below. These designs are selected according to the wind turbine starting mode and not switchgear selection. (Some other DFIG schemes including Delta–Star connection could be suitable as well, but we don't address these cases in the following tables).

Based on our experience, we give a reminder that in these schemes the main contactor between transformer and generator is mandatory.

The tables below give Schneider Electric's recommendations for selection of main switchgear @ 690 V @ T° = 50°C inside the cabinet. The proposed combinations of Compact or Masterpact circuit breakers and Tesys F contactors provide type 2 coordination up to 25 kA and type 1 for higher short-circuit current (according to IEC60947-4-1).

Circuit breaker trip unit selection and setting are described in section "Masterpact trip unit selection".

Tesys F Contactors, thermal current from 40 °C to 60 °C

As T° may be different, we also give the T° de-rating for the products in question

	LC1 F630	LC1 F1250	LC1 F1400	LC1 F780	LC1 F1700	LC1 F2100	LC1 F2100 + LA9F2100	LC1 F2600	LC1 F2600 + LA9F2600	2 x LC1 F2100 //(1)
Minimum Copper Bar / pole (mm)	2x60x5	2x50x10	2x100x5	2x100x5	3x100x5	4x100x5	4x100x5	3x100x10	3x100x10	4x100 x 5
Ith (A) 40 °C	1000	1260	1400	1600	1700	2050	2100	2600	2600	3280
Ith (A) 50 °C	950	1170	1300	1500	1600	1900	1950	2550	2600	3040
Ith (A) 60 °C	850	1050	1200	1350	1450	1700	1750	2500	2600	2720

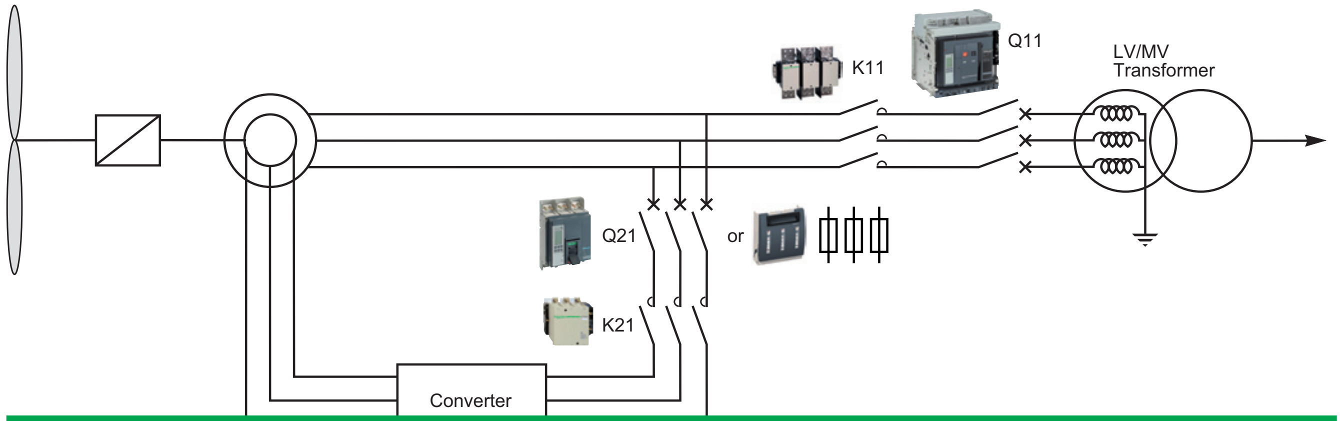
***(1)** When contactors are used in parallel installation recommendations (distances between contactors, etc.) shall be complied with.*

Fixed Compact & Masterpact, uninterrupted current from 40 °C to 60 °C

	Compact NS800LB	Masterpact NT10L1	Masterpact NT16H2T	Masterpact NW25H1T	Masterpact NW32H1T
Icu @ 690 V	**75 kA(2)**	**25 kA**	**42 kA**	**65 kA**	**65 kA**
Ith (A) 40 °C	**800 A**	**1000 A**	**1600 A**	**2500 A**	**3200 A**
Minimum bar connection / pole	2 x 50 x 5 mm 1 x 50 x 10 mm	3 x 50 x 5 mm 1 x 63 x 10 mm	3 x 80 x 5 mm 2 x 63 x 10 mm	4 x 100 x 5 mm 2 x 100 x 10 mm	4 x 100 x 10 mm
Ith (A) 50 °C	**800 A**	**1000 A**	**1600 A**	**2500 A**	**3200 A**
Minimum bar connection / pole	2 x 50 x 5 mm 1 x 50 x 10 mm	3 x 50 x 5 mm 2 x 50 x 10 mm	3 x 80 x 5 mm 2 x 63 x 10 mm	4 x 100 x 5 mm 2 x 100 x1 0 mm	4 x 100 x 10 mm
Ith (A) 60 °C	**800 A**	**1000 A**	**1550 A**	**2500 A**	**3200 A**
Minimum bar connection / pole	2 x 50 x 5 mm 1 x 50 x 10 mm	3 x 63 x 5 mm 2 x 50 x 10 mm	3 x 80 x 5 mm 2 x 63 x 10 mm	4 x 100 x 5 mm 3 x 80 x 10 mm	4 x 100 x 10 mm

Fixed circuit breaker, front or rear horizontal connection; for details or other connections, see Masterpact or Compact catalogue.
***(2)** 75 kA Icu is not necessary but LB type is necessary for coordination with contactor.*

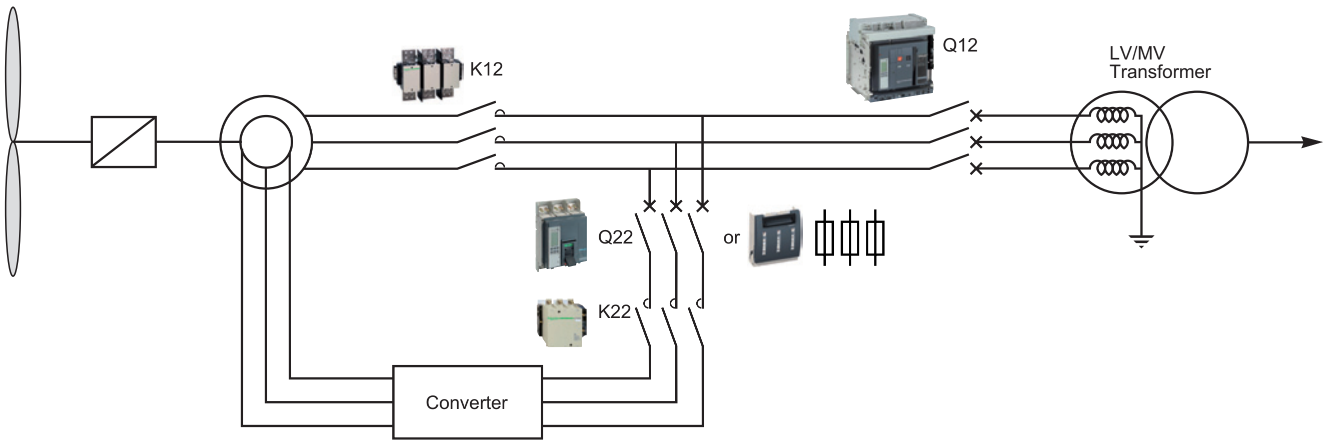
DFIG with main circuit breaker and contactor between transformer and rotor converter circuit



Wind Turbine (MW)	Max short-circuit current	Q11	K11 Main contactor	K11 Ith 50 °C	Q21	K21	K21 Ith 50 °C
0.85 MW @ 690 V	< 20 kA	NS800LB / NT10L1	LC1F630	950 A	ISFT250 NSX400HB1	LC1F185 LC1F330	275 A 300 A
1 MW @ 690 V	< 20 kA	NT10L1	LC1F780	1500 A	ISFT250 NSX400HB1	LC1F185 LC1F330	275 A 300 A
1.5 MW @ 690 V	< 25 kA	NT16H2T	LC1F780 LC1F1700	1500 A 1600 A	ISFT400 NSX400HB1	LC1F330 LC1F330	360 A
2 MW @ 690 V	< 36 kA	NW25H1T or NW25H1TH	LC1F2100	1900 A	ISFT630 NS630LB	LC1F500 LC1F500	580 A
2.1 MW @ 690 V	< 36 kA	NW25H1T or NW25H1TH	LC1F2100 + LA9F2100	1950 A	ISFT630 NS630LB	LC1F500 LC1F500	580 A
2.5 MW @ 690 V	< 42 kA	NW32H1T or NW32H1TH	LC1F2600	2550 A	ISFT630 NS630bLB	LC1F630	850 A
3 MW @ 690 V	< 50 kA	NW32H1T or NW32H1TH	2 x LC1F2100 (1)	3040 A	NS800LB	LC1F630	850 A

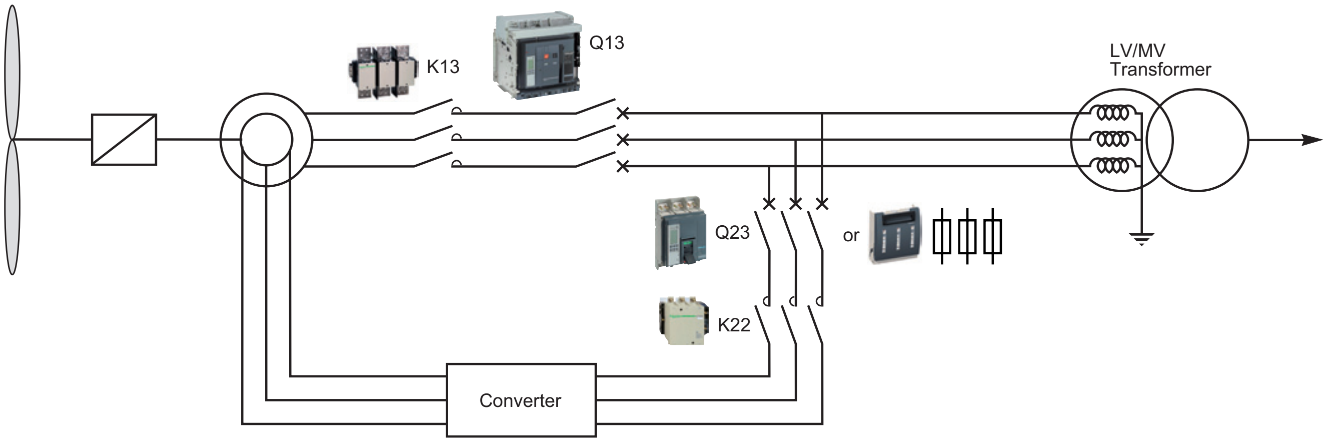
***(1)** type 1 coordination*

DFIG with main circuit breaker between transformer and rotor converter circuit and contactor between rotor converter circuit and stator



Wind Turbine (MW)	Max short-circuit current	Q12	K12 Main contactor	K12 Ith 50 °C	Q22	K22	K22 Ith 50 °C
0.85 MW @ 690 V	< 20 kA	NS800LB / NT10L1	LC1F630	950 A	ISFT250 NSX400HB1	LC1F185 LC1F330	275 A 300 A
1 MW @ 690 V	< 20 kA	NT10L1	LC1F630	950 A	ISFT250 NSX400HB1	LC1F185 LC1F330	275 A 300 A
1.5 MW @ 690 V	< 25 kA	NT16H2T	LC1F780 LC1F1700	1500 A 1600 A	ISFT400 NSX400HB1	LC1F330 LC1F330	360 A
2 MW @ 690 V	< 36 kA	NW25H1T or NW25H1TH	LC1F1700 LC1F2100	1600 A 1900 A	ISFT630 NS630LB	LC1F500 LC1F500	580 A
2.1 MW @ 690 V	< 36 kA	NW25H1T or NW25H1TH	LC1F2100	1900 A	ISFT630 NS630LB	LC1F500 LC1F500	580 A
2.5 MW @ 690 V	< 42 kA	NW32H1T or NW32H1TH	LC1F2600	2550 A	ISFT630 NS630bLB	LC1F630	850 A
3 MW @ 690 V	< 50 kA	NW32H1T or NW32H1TH	LC1F2600 + LA9F2600	2600 A	NS800LB	LC1F630	850 A

DFIG with main circuit breaker and contactor between rotor converter circuit and stator



Wind Turbine (MW)	Max short-circuit current	Q13	K13 Main contactor	K13 Ith 50 °C	Q23	K23	K23 Ith 50 °C
0.85 MW	< 20 kA	NS800LB	LC1F630	950 A	ISFT250 NSX400HB1	LC1F185 LC1F330	275 A 350 A
1 MW	< 20 kA	NT10L1	LC1F630	950 A	ISFT250 NSX400HB1	LC1F185 LC1F330	275 A 350 A
1.5 MW	< 25 kA	NT16H2T	LC1F780 LC1F1700	1500 A 1600 A	ISFT400 NSX400HB1	LC1F330 LC1F330	430 A
2 MW	< 36 kA	NW25H1T or NW25H1TH	LC1F1700 LC1F2100	1600 A 1900 A	ISFT630 NS630LB	LC1F500 LC1F500	580 A
2.1 MW	< 36 kA	NW25H1T or NW25H1TH	LC1F2100	1900 A	ISFT630 NS630LB	LC1F500 LC1F500	580 A
2.5 MW	< 42 kA	NW32H1T or NW32H1TH	LC1F2600	2550 A	ISFT630 NS630bLB	LC1F630 LC1F630	850 A
3 MW	< 50 kA	NW32H1T or NW32H1TH	LC1F2600 + LA9F2600	2600 A	NS800LB	LC1F630	850 A

The selection of circuit breaker and contactor shall be checked according to the true characteristics of each wind turbine (voltage, current, ambient T°, connections, products arrangement in the cubicle).

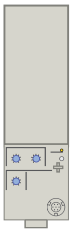
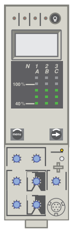
Additional information regarding Masterpact ACB accessories & Trip unit

Masterpact Accessories

Even if the main circuit breaker is not used for frequent connection and disconnection according to the wind speed thanks to the contactor, the circuit breaker can be tripped by wind turbine protection (emergency stop, transformer protection, etc.) or by its own protective device (short-circuit, overload or ground fault protection). As the wind turbine may be operated without staff on site we recommend that the circuit breaker can be remotely operated as well.

The following function should be added to the main circuit breaker:
- Motor operation
- Remote Reset
- Operation counter

Masterpact Trip Unit selection

Protections / Measurement	No measurement	A Current	P Current / Voltage Power	H Current / Voltage Power / Harmonic
				
Long time Short time (LS)	**2.0**	**2.0 A**		
Long time Short time Instantaneous (LSI)	**5.0**	**5.0 A**	**5.0 P**	**5.0 H**
Long time Short time Instantaneous Ground Fault (LSIG)		**6.0 A**	**6.0 P**	**6.0 H**

"LSI" protective devices are generally necessary to meet setting requirements (see next page).

Ground fault may be used according to habits. Usually the main transformer neutral is solidly grounded so LSI protection is sufficient.

Type P and H could be used if required, but as these trip units measure voltage and the voltage in wind turbines during transient states could exceed 690V, the use of an external VT is mandatory.

Trip Unit settings and Low Voltage Ride-Through

As many grid codes now require Low Voltage Ride-Through capability, the settings of the main circuit breaker should be selected in order not to trip during grid disturbances (short-circuit, voltage drop, etc.) that could induce transient over-current supplied by generator. The behavior of a Doubly-Fed Induction Generator in voltage drop situations depends on converter regulation and rotor resistive crowbar system control. Usually the current fed by this type of generator in the event of a grid fault is not as high as with a squirrel cage induction generator. On the other hand, the contactor shall be properly protected against short-circuit.

Settings shall be studied according to each design; we indicate below the maximum settings to cope with potential current transient overreach and properly protect contactor for type 2 coordination.

Circuit breaker	Contactor	In	Ir	Tr max	Isd max (x Ir)	Tsd max	Ii max (xIn)
NS800LB	LC1F630	800	0.8-1	4 s	7	0.2 ON	8
NT10L1	LC1F630	1000	0.8-1	4 s	5	0.2 ON	6
NT16H2T	LC1F780/ LC1F1700	1600	0.8-1	4 s	5	0.2 ON	6
NW25H1T or NW25H1TH	LC1F1700 / LC1F2100	2500	0.8-1	2 s	3	0.2 ON	4
NW25H1T or NW25H1TH	LC1F2100	2500	0.8-1	2 s	4	0.2 ON	4
NW32H1T or NW32H1TH	LC1F2600	3200	0.8-1	2 s	4	0.2 ON	4
NW32H1T or NW32H1TH	2 x LC1F1700	3200	0.8-1	2 s	4	0.2 ON	4
NW32H1T or NW32H1TH	2 x LC1F2100	3200	0.8-1	2 s	6	0.2 ON	6

If higher settings are used, Type 1 coordination is ensured in all cases.

In some cases, a long-time rating plug could be useful.

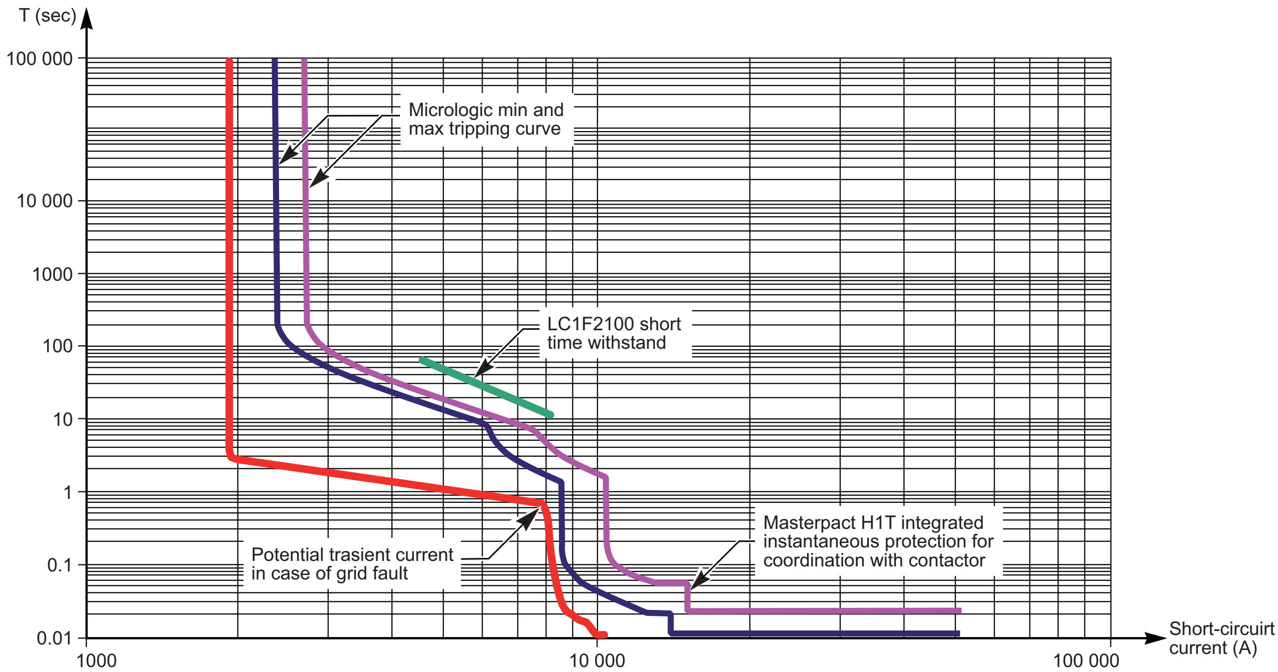
Long-time rating plug

Four interchangeable plugs may be used to limit the long-time threshold setting range for higher accuracy.
The time delay settings indicated on the plugs are for an overload of 6 Ir. As standard, control units are equipped with the 0.4 to 1 plug.

Setting ranges										
Standard	Ir = In x...	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.98	1
Low-setting option	Ir = In x...	0.4	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.8
High-setting option	Ir = In x...	0.80	0.82	0.85	0.88	0.90	0.92	0.95	0.98	1
Off plug		No long-time protection (Ir = In for Isd setting)								

Important: long time rating plugs must always be removed before carrying out insulation or dielectric withtand tests.
(Taken from Masterpact catalogue Ref. LVPED208008EN p. A20).

Example of tripping curve with indicated settings for Masterpact NW25 Micrologic 5 for 2MW wind turbine
(Ir = 2500 A / Isd = 3 Ir Tr = 2 s Tsd = 0.2 s I2t On Ii = In)



Wind turbine with indirect grid connection design

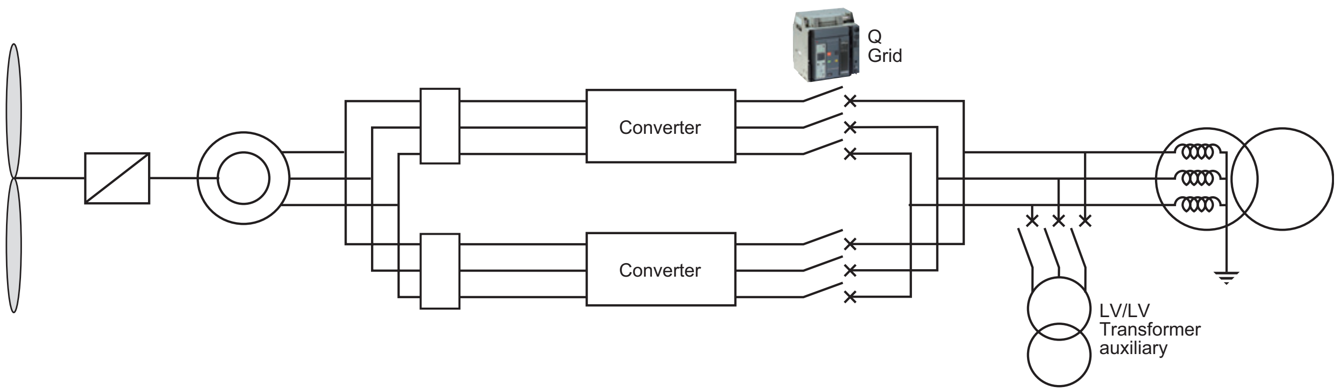
When these principles are used for rated powers > 1 MW, several converters are connected in parallel

Common aspect of all designs: Grid side Breaker

If the converters remain connected to the grid even in non-production period (wind too low or too high), the grid switchgear can be a circuit breaker alone.

If the converter is disconnected from the grid in non-production periods (wind too low or too high), a contactor shall be used alongside the circuit breaker.

Please consult us.

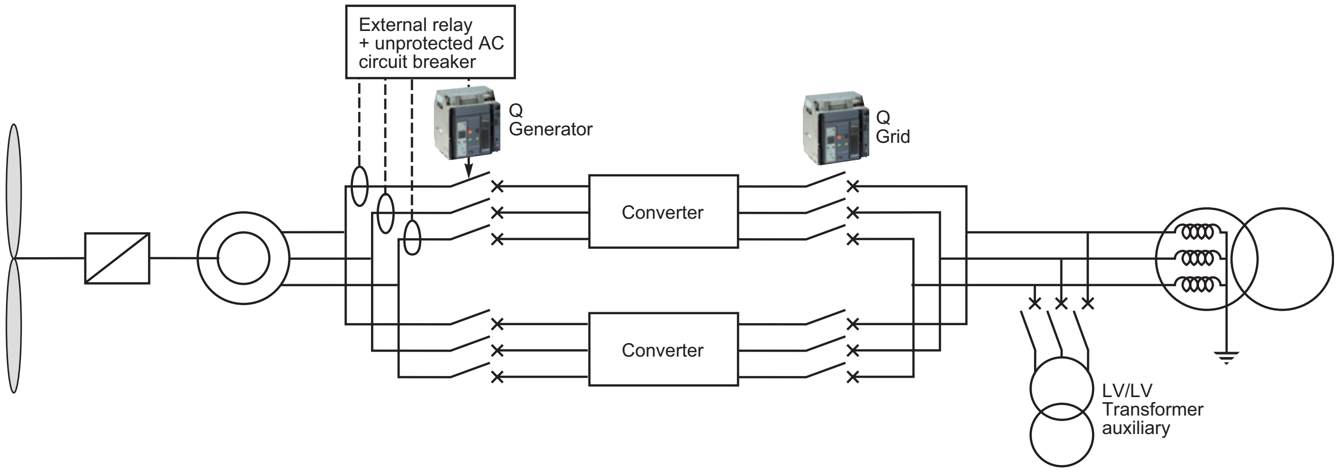


Synchronous generator & gearbox

Stator frequency 15 Hz – 150 Hz.
AC range switchgear can be used on generator side from current interruption standpoint, but trip unit cannot operate over the full frequency range and temperature rise issues could occur at high frequency.

Solution: Unprotected AC circuit breaker + external relay or fuses.

Please consult us.

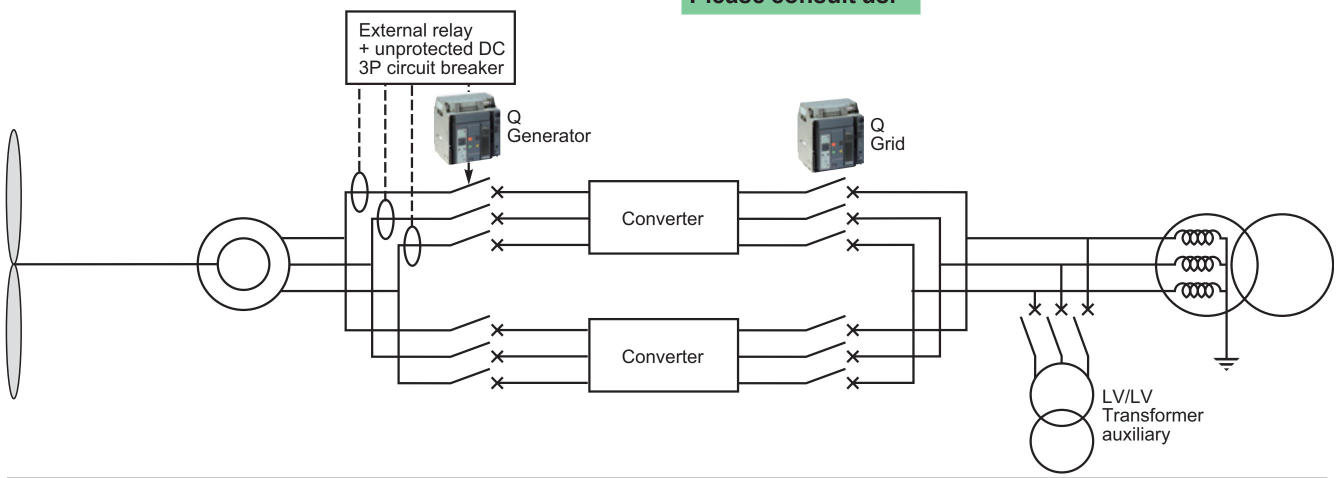


Synchronous generator & NO gearbox

Stator frequency 5 Hz – 20 Hz
AC range switchgear CANNOT be used on generator side from current interruption standpoint.

Solution: Unprotected DC circuit breaker + external relay or fuses.

Please consult us.



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