

# Wind Farm Grid Connection Code

in addition to the  
Egyptian Transmission Grid Code (ETGC)



This document is the revised draft of the English version of the Wind Farm Grid Connection Code that has been reviewed and enhanced by professional personnel in relevance to each section of the code.

**Version: Revised Draft**

**June, 2013**

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## **1 INTRODUCTION**

Notwithstanding the provisions of the Egyptian Transmission System Code (the Grid Code), this Wind Farm Grid Connection Code specifies the special requirements for the connection of Wind Farms to the High and Extra High Voltage transmission system (the Grid). This Wind Farm Grid Connection and the Egyptian Transmission System Code (ETSC) are two complementary documents.

## **2 OBJECTIVE**

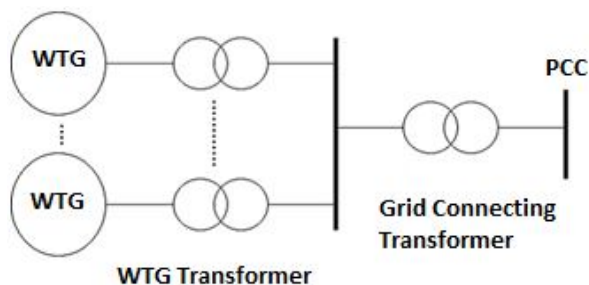
The objective of the Wind Farm Grid Connection Code is to ensure that any new or modified Wind Farms, when established, shall neither suffer unacceptable effects due to its connections to the Grid nor impose unacceptable effects on the Grid.

## **3 SCOPE**

This Wind Farm Grid Connection Code shall apply to Wind Farms that are connected to the Grid after [insert date].

Replacement of and radical changes in existing wind turbine generators shall be considered as new units. All changes relating to the properties of wind turbine generators mentioned in this Wind Farm Grid Connection Code shall basically be considered as essential. The Grid Operator shall determine whether changes are essential.

## 4 DEFINITIONS

<b>Available Active Power</b>	The amount of active power that the Wind Farm could produce based on current wind conditions.
<b>Connection Agreement</b>	An agreement between the Wind Farm and the Grid Operator setting out the terms relating to the connection of the Wind Farm to the Grid.
<b>Extra High Voltage</b>	Voltage levels greater than 132 kV.
<b>Grid</b>	The High Voltage and Extra High Voltage transmission system of interconnected transmission lines, substations, and related facilities.
<b>Grid Code</b>	The Egyptian Transmission System Code (ETSC) – Draft version.
<b>Grid Connection Point</b>	<p>The point of common coupling (PCC) where all wind turbine generators (WTG) of a Wind Farm are connected to the Grid, as shown in the following figure.</p>  <p>The diagram shows two wind turbine generators (WTG) on the left, each connected to a transformer labeled 'WTG Transformer'. These transformers are connected to a common busbar. This busbar is connected to a 'Grid Connecting Transformer', which is then connected to a vertical line representing the 'PCC' (Point of Common Coupling).</p>
<b>Grid Operator</b>	The entity responsible for grid operations. Its functions will be carried out by a unit of the Egyptian Electricity Transmission Company (EETC).
<b>High Voltage</b>	Voltage levels from 33 kV up to 66 kV.
<b>Rated Power of a Wind Farm</b>	The maximum active output power of the Wind Farm under standard operating conditions.
<b>Rated Power of a wind turbine generator</b>	The maximum active output power, which a wind turbine generator is constructed to produce continuously under standard operating conditions.
<b>Wind Farm</b>	A collection of one or several wind turbine generators with equipment (e.g. internal network for connection to the Grid Connection Point).

## 5 GRID CONNECTION REQUIREMENTS

### 5.1 General Requirements

The requirements outlined below are the minimum requirements and, unless otherwise stated, must be fulfilled by a Wind Farm at the Grid Connection Point.

In case during the operation of the Wind Farm does not fulfill the requirements given in this Wind Farm Grid Connection Code, the Grid Operator is authorized to disconnect the Wind Farm from the Grid. In such cases the reconnection of the Wind Farm must be agreed with the Grid Operator.

The Grid Operator is authorized to change one or more of the following requirements or to give further requirements, if it is necessary for a safety and stable operation of the Grid.

### 5.2 Disconnection from the Grid

#### 5.2.1 Voltage ranges

- 1) In case of a deviation of the voltage at the Grid Connection Point from its permissible voltage range, the Wind Farm shall be able to deliver Available Active Power according to wind conditions when the voltage at the Grid Connection Point remains within the ranges specified by Table 5.1. Any automatic disconnection of the Wind Farm from the Grid shall be prohibited due to the deviation within the voltage ranges, expressed by the voltage at the Grid Connection Point related to nominal voltage (per unit), and within the time periods specified by Table 5.1.
- 2) Notwithstanding the provisions of point 1), a Wind Farm shall be capable of automatic disconnection from the Grid at specified voltages, if required by the Grid Operator. The terms and settings for automatic disconnection shall be agreed with the Grid Operator, see section 6 (GRID PROTECTION).

**Table 5.1: Minimum time periods**

<b>Voltage range</b>	<b>Time period for operation</b>
0.85 per unit – 0.90 per unit	Unlimited
0.90 per unit – 1.10 per unit	Unlimited
1.10 per unit – 1.15 per unit	30 minutes

#### 5.2.2 Frequency ranges

In case of a deviation of the grid frequency from its permissible value, any automatic disconnection of the Wind Farm from the Grid shall be prohibited due to the deviation within the frequency range of 47.5 Hz until 51.5 Hz.

### 5.3 Power Quality

All the Wind Farms connected to the Grid shall endeavor to maintain the voltage wave-form quality at the Grid Connection Point. The Wind Farms shall comply with the requirements of Section 5.2 (Power Quality Standards) of the Grid Code, with the following exceptions.

#### 5.3.1 Harmonics

The maximum levels of harmonic distortion on the Grid Connection Point from the Wind Farm shall be as follows:

**Table 5.2: Maximum level of harmonic voltage distortion**

Voltage Level	Level of harmonic voltage distortion	
	Odd harmonics %	Total harmonics %
More than 161KV	1.0	1.5
69.001-161 KV	1.5	2.5
Up to 69 KV	3.0	5.0

See IEEE 519 [2]

**Table 5.3: Maximum level of integer harmonic current distortion in the frequency range up to 2 kHz**

Short circuit ratio	Maximum integer harmonic current distortion as percentage of $I_L$					Total* distortion
	Odd harmonic distortion					
$I_{sc}/I_L$	<11	≥11 to <17	≥17 to <23	≥23 to <35	≥35	
<50	2.0	1.0	0.75	0.3	0.15	2.5
≥50	3.0	1.5	1.15	0.45	0.22	3.75

\* The maximum level of harmonics current distortion of all generating equipment irrespective of the actual  $I_{sc}/I_L$

$I_{sc}$ : The maximum short circuit current at Grid Connection Point

$I_L$ : The maximum load current (fundamental frequency component) at the Grid Connection Point

The maximum level of even harmonics is 25% of odd harmonics.

**Table 5.4: Maximum level of harmonic current distortion in the frequency range above 2 kHz**

Short circuit ratio	Maximum harmonic current distortion in the frequency range above 2 kHz as percentage of $I_L$						
	$I_{sc}/I_L$	$2\text{kHz} \leq f < 3\text{kHz}$	$3\text{kHz} \leq f < 4\text{kHz}$	$4\text{kHz} \leq f < 5\text{kHz}$	$5\text{kHz} \leq f < 6\text{kHz}$	$6\text{kHz} \leq f < 7\text{kHz}$	$7\text{kHz} \leq f < 9\text{kHz}$
<50		0.3	0.25	0.2	0.15	0.12	0.1
$\geq 50$		0.6	0.5	0.4	0.3	0.25	0.2

See IEEE 519 [2]

**Table 5.5: Maximum level of interharmonic current distortion up to 2 kHz**

Short circuit ratio	Maximum interharmonic current distortion as percentage of $I_L$				
	$I_{sc}/I_L$	<0.5kHz	$0.5\text{kHz} \leq f < 1\text{kHz}$	$1\text{kHz} \leq f < 1.5\text{kHz}$	$1.5\text{kHz} \leq f < 2\text{kHz}$
<50		0.3	0.25	0.15	0.1
$\geq 50$		0.45	0.4	0.25	0.2

### 5.3.2 Flicker

The flicker, caused by the Wind Farm at the Grid Connection Point, must be within the following limits, see IEC61000-3-7 [3]:

Short term (10 minutes):  $P_{st} \leq 0.35$

Long term (2 hours):  $P_{lt} \leq 0.25$

$P_{lt}$  Long term flicker factor over time periods of 2 hours

$P_{st}$  Short term flicker factor over time periods of 10 minutes

### 5.3.3 Voltage unbalance

Voltage unbalance is defined as the deviation between the highest and lowest line voltage divided by the average line voltage of three phases. Wind Farms shall be able to withstand voltage unbalance not exceeding 2%.

### 5.3.4 Voltage fluctuations

The voltage fluctuations in a Wind Farm can occur because of the switching operations (capacitor banks, wind turbine generator start/stop), inrush currents during wind turbine generator starting etc. The maximum voltage fluctuation is 5% from the voltage nominal value.



### 5.3.5 Voltage change

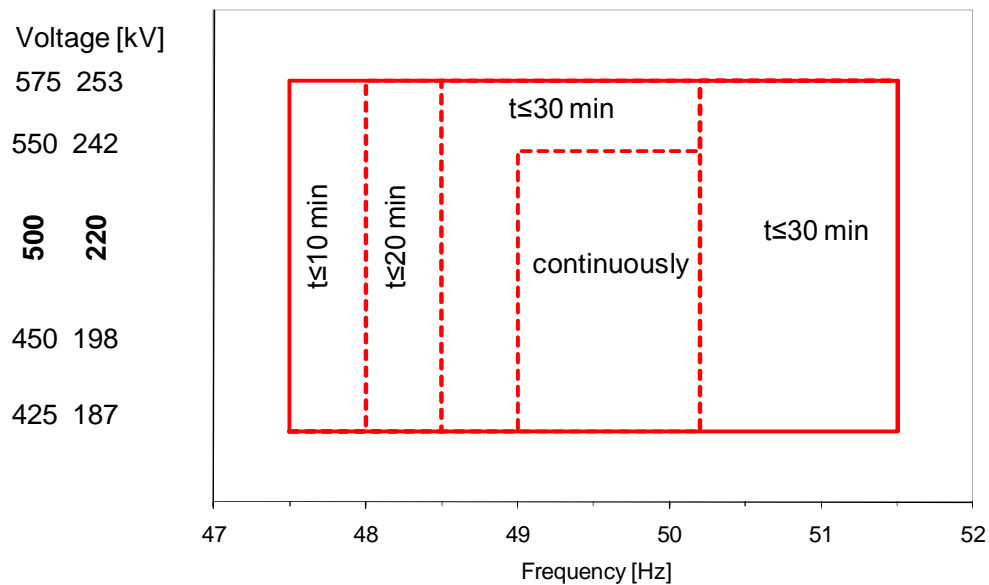
Due to the operation of the Wind Farm the voltage at the Grid Connection Point shall not change for more than  $\pm 5\%$  of nominal voltage.

## 5.4 Active power control

### 5.4.1 Active power output

The Wind Farm is not allowed to reduce output power within the frequency range of 47.5 Hz up to 50.2 Hz due to variations in the grid frequency or in the grid voltage at the Grid Connection Point for the time periods given in Figure 5.1.

**Figure 5.1: Requirements on the output power of the Wind Farm in case of grid frequency and grid voltage variations (quasi-stationary observation)**



### 5.4.2 Active power reduction due to overfrequency

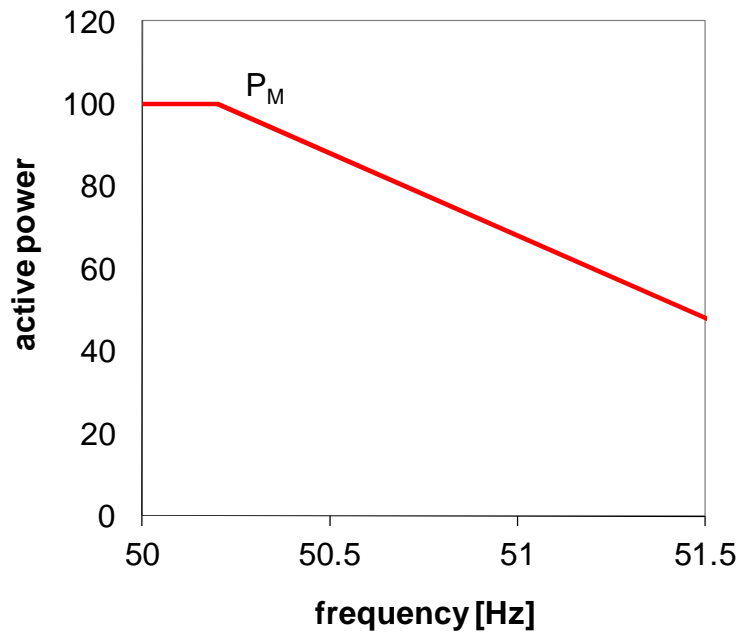
For grid frequencies in the range from 50.2 Hz to 51.5 Hz the wind turbine generators of the Wind Farm have to reduce active output power with a rate of 40% of actual active output power per Hertz, see Figure 5.2.

The output power must be reduced by:

$$\Delta P = 0.4 * PM * \frac{\Delta f}{Hz} \quad \text{Equation 5.1}$$

PM: actual output power before the grid frequency exceeds 50.2 Hz

$\Delta f$ : actual grid frequency minus 50.2 Hz

**Figure 5.2: Active power reduction due to overfrequency**

### 5.4.3 Active power set-point control

On request of the Grid Operator the Wind Farm must reduce the active output power, amongst others, in the following cases:

- 1) potentially risk for a safety grid operation
- 2) bottlenecks and risk of overloading in the Grid
- 3) risk of islanding
- 4) loss of the dynamical or statical grid stability
- 5) maintenance.

The Wind Farm must have an input signal for a set-point value at the Grid Connection Point, to reduce the active output power. The Grid Operator will provide the set-point signal. In case of an active output power reduction the Wind Farm must follow the set-point signal of the Grid Operator within one minute. The Wind Farm must be able to reduce the active output power within steps of maximum 10 % of Rated Power of the Wind Farm. Only for output power below 10 % of Rated Power the Wind Farm can be disconnected from the Grid. The rate of the reduction of the active output power shall be 20 % of Rated Power of the Wind Farm per minute.

Details of the technical solution of the set-point signal (interface, protocol) must be agreed with the Grid Operator in the Connection Agreement.

## 5.5 Start-up of the Wind Farm

During the start-up of the Wind Farm or of the wind turbine generators of the Wind Farm the increase of the active power shall not exceed 10 % of the Rated Power of the Wind Farm per minute.

## 5.6 Conditions for connection

The wind turbine generators of the Wind Farm shall only connect to the Grid (start-up), if the frequency and the voltage at the Grid Connection Point are within the following limits:

Frequency:  $48 \text{ Hz} \leq f \leq 50.2 \text{ Hz}$

Voltage:  $0.95 \text{ per unit} \leq U \leq 1.05 \text{ per unit}$

## 5.7 Reactive power control

The Wind Farm must be able to control reactive power at the Grid Connection Point in a range of 0.95 lagging to 0.95 leading at max. active power and according to fig. 5.3. The reactive power provision capability requirement applies at the high-voltage terminals at the Grid Connection Point of the Wind Farm.

The Wind Farm must be able to control reactive power as follows:

- 1) Set-point control of reactive power Q
- 2) Set-point control of power factor ( $\cos \varphi$ )
- 3) Fixed power factor ( $\cos \varphi$ )
- 4) Characteristic: power factor as a function of active power output of the Wind Farm,  $\cos \varphi (P)$
- 5) Characteristic: reactive power as a function of voltage,  $Q(U)$

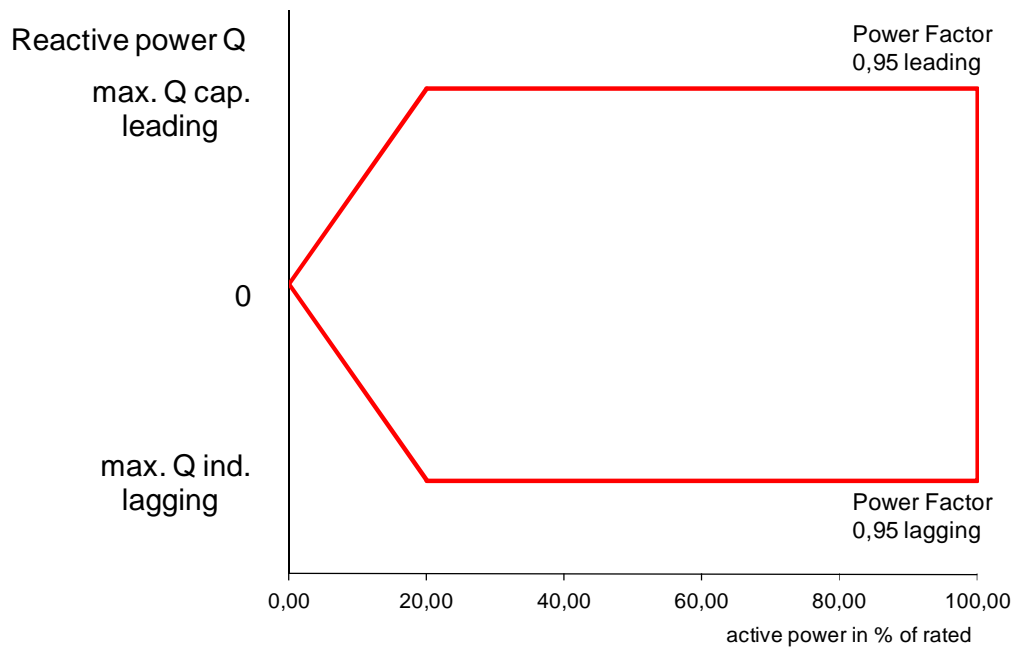
The mode of operation of reactive power control will be determined by the Grid Operator in the Connection Agreement.

The Wind Farm must have an input signal for a set-point value at the Grid Connection Point, to control reactive power or  $\cos \varphi$  of the Wind Farm. The Grid Operator will provide the set-point signal. The Wind Farm must follow the set-point signal of the Grid Operator within one minute.

With regard to reactive power capability below Rated Capacity of the Wind Farm, when operating at an active power output below the Rated Capacity of the Wind Farm ( $P < P_{\max}$ ), the Wind Farm shall be able to be operated in every possible operating point in the P-Q Diagram, see Figure 5.3. Even at reduced active power output, reactive power supply at the high-voltage terminals at the Grid Connection Point shall fully correspond to the P-Q-Diagram, taking the auxiliary service power, the losses of the transformers and the Wind Farm cabling into account.

The maximum Q cap. and the maximum Q ind. in Figure 5.3 are calculated from the Rated Power of the Wind Farm and the power factor of 0.95.

**Figure 5.3:P-Q Diagram**

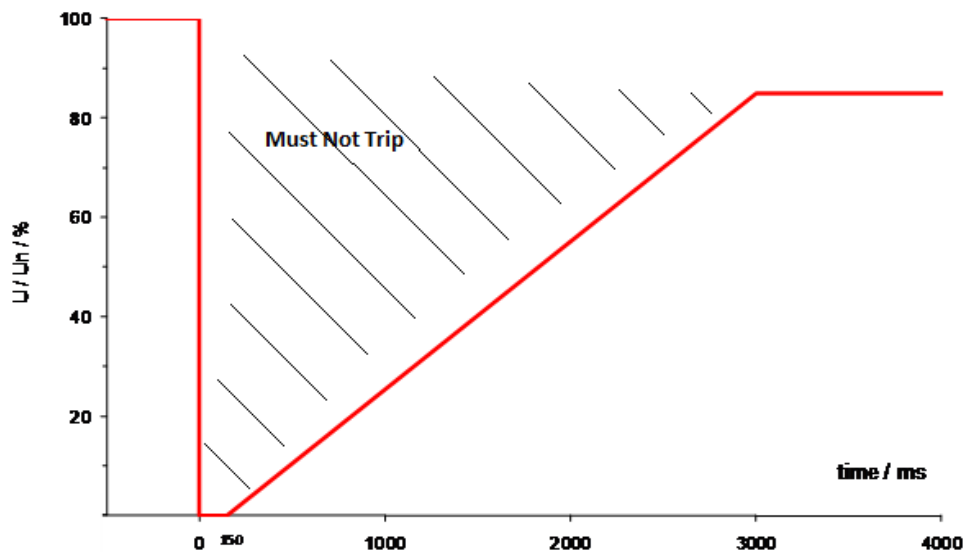


### 5.8 Temporary voltage drops

Wind turbine generators are not allowed to disconnect from the Grid in case of short voltage drops due to grid faults:

For temporary voltage drops, where at least one of the three phase-to-phase voltages is above the red curve in Figure 5.4, wind turbine generators have to ride-through the grid fault without disconnection from the Grid.

**Figure 5.4:Fault ride through profile for a Wind Farm**

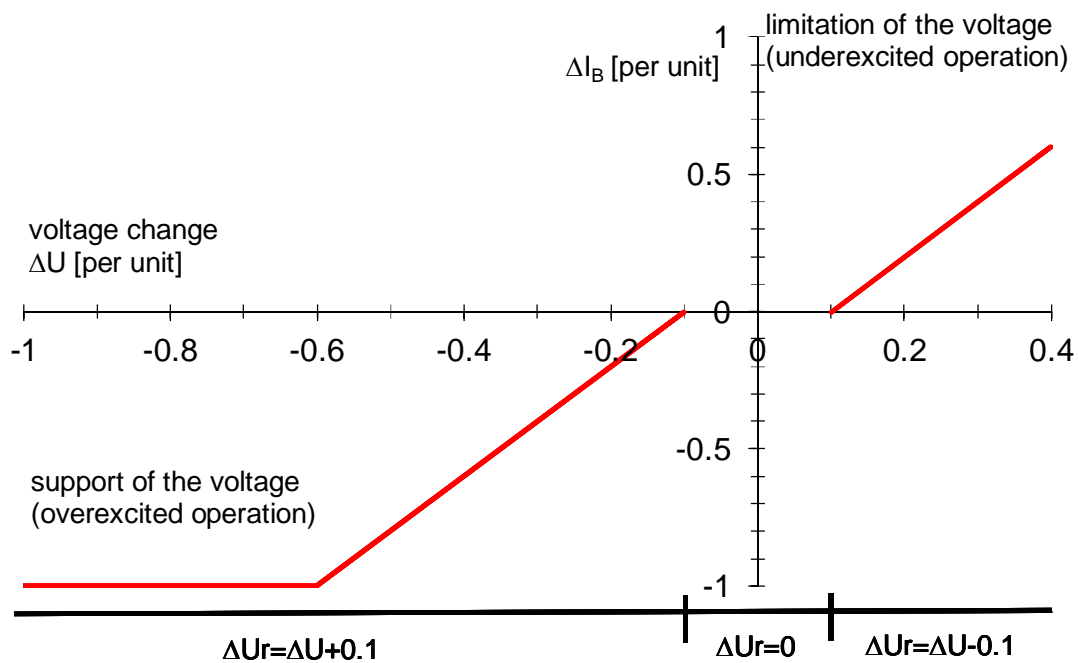


For voltage drops above the red curve the Wind Farm is not allowed to disconnect from the Grid.

During the temporary voltage drop wind turbine generators must fulfill the following requirements concerning reactive power or reactive current:

- 1) For 3-phase faults the wind turbines must inject reactive current according to Figure 5.5 and Equation 5.2 and Equation 5.3 for the time period 150 ms after the beginning of the fault until fault clearance.

**Figure 5.5: Current injection during the fault**



The red line represents the required minimum reactive current, expressed by the ratio of the reactive current and the nominal reactive current in per unit, against the voltage drop, expressed by the ratio of the actual voltage value and its nominal value in per unit at the network connection point.

$$\frac{\Delta I_B}{I_N} = k \cdot \frac{\Delta U_r}{U_N} \quad \text{Equation 5.2}$$

$$\Delta U = U - U_0 \quad \text{Equation 5.3}$$

Variables:

$U_N$ :	rated voltage
$I_N$ :	rated current
$U$ :	voltage during fault
$\Delta I_B$ :	required reactive current change during fault
$U_0$ :	pre-fault voltage
$\Delta U_f$ :	relevant voltage change during the fault

The factor  $k$  shall be adjustable in the range from 0 to 4. The preferable setting of  $k$  shall be  $k=2$ .

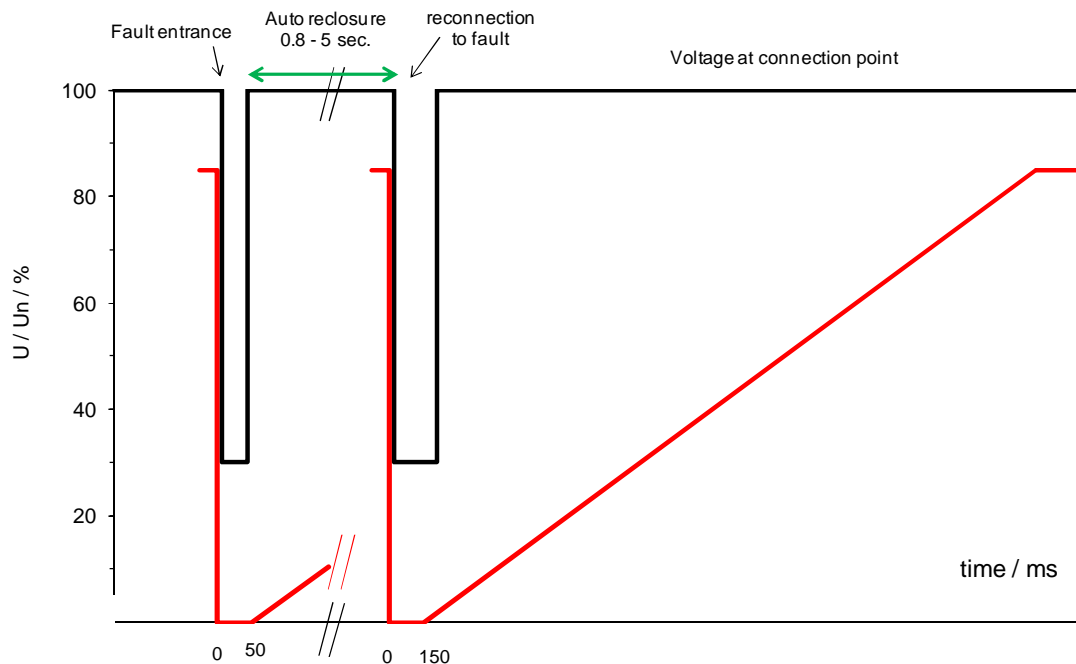
- 2) For 2 phase and 1phase faults for all wind turbine generators the following is required: During the time period 150 ms after the fault entrance until fault clearance the consumption of reactive power must be below 40 % of Rated Power of the wind turbine generator and the consumption of active power must be below 30 % of Rated Power of the wind turbine generator in each grid cycle (20 ms).

After fault clearance the active power output of the Wind Farm must reach the same level as before the fault within a time period of 10 s after fault clearance.

After fault clearance the consumption of reactive power of the Wind Farm must be equal or below the consumption of reactive power before the fault.

For non-successful auto-reclosures two successive temporary voltage drops can occur, as shown in Figure 5.6. The wind turbine generators have to ride-through both temporary voltage drops according to the requirements given above in Figure 5.4.

**Figure 5.6: Temporary voltage drops due to a non-successful auto-reclosure**



In case of automatic reclosing applied, the maximum permissible times are as follows:

**Table 5.6: Auto-reclosure time range**

Case	500 kV –Single phase trip and reclose	500 kV –Three phase trip and reclose	220 kV –Three phase trip and reclose
<b>Fault Occurrence</b>	60 ms	60 ms	80 ms
<b>Single phase trip</b>	80 ms		
<b>Single phase reclose after</b>	800 ms		
<b>Evolving fault clearance</b>	200 ms		
<b>Permanent fault</b>	60:80ms		
<b>Three phase trip</b>		80 ms	100 ms
<b>Three phase reclose</b>		5000:6000ms	500:1000ms
<b>Reclaim time</b>	Not less than 200 sec		

## 6 GRID PROTECTION

The grid protection of the Wind Farm shall be performed according to the Protection Code of the Grid Code.

The settings of the grid protection device in the wind turbine generators of the Wind Farm must conform to Table 6.1, unless agreed otherwise with the Grid Operator in the Connection Agreement.

**Table 6.1: Setting of the grid protection at the wind turbine generators**

Function	Setting range	Recommended settings	
		Level	Settling time
Overvoltage $U \gg$	$1.00 - 1.30 U_n$	$1.20 * U_n$	$\leq 3 \text{ s}$
Undervoltage $U <$	$0.10 - 1.00 U_n$	$0.80 * U_n$	3 s
Undervoltage $U \ll$	$0.10 - 1.00 U_n$	$0.30 * U_n$	300 ms - 1 s
Overfrequency	50 - 52 Hz	51.5 Hz	$\leq 100 \text{ ms}$
Underfrequency	47.5 - 50 Hz	47.5 Hz	$\leq 500 \text{ ms}$

$U_n$ : rated voltage

## **7 REAL-TIME DATA**

### **7.1 Real Time Data Measuring and Monitoring**

The Wind Farm must have technical equipment at the Grid Connection Point to transfer the following information for the power system management systems furnished with a real-time stamp:

Measured values from the Wind Farm:

- 1) Active power
- 2) Reactive power
- 3) 3 phase Voltages ( magnitude and phase )
- 4) 3 phase Currents for magnitude and phase
- 5) Frequency
- 6) Wind speed
- 7) Temperature
- 8) Generator transformer tap position.

Status signals from the Wind Farm:

- 1) Status from switching equipment: circuit breakers, disconnectors, earthings switches and tap changers, if required for operation or system evaluation
- 2) Protection signals at the grid side

Set-point values, given from the Grid Operator to the Wind Farm:

- 1) Active power set-point
- 2) Reactive power set-point or power factor set-point
- 3) Status: Wind Farm is not allowed to start
- 4) Status: Wind Farm must disconnect

The interface and the protocol as well as the exact scope of the process data being exchanged will be jointly defined, see section 5.4.3.

A Disturbance Recording System (DRS) with phasor measurement supports the IEEE C37.118-2005 standard equipped with GPS source with minimum accuracy 1  $\mu$ sec should be installed at the Grid Connection Point for real-time monitoring and measuring for voltage, current magnitude and phase, frequency, active and reactive power....etc. Detailed specifications of the Disturbance Monitoring system with PMU and Power Quality measurement at the Connection Point will be amended to the connection contract.

### **7.2 Real Time Control**

Also the Grid Operator shall be able to submit control signals to the common control system of the wind farm according to the connection agreement. The wind farm operator has to follow the Grid Operator's instructions and he has to decide which specific wind turbine generator (or generators) has (have) to be manipulated (load change, switch off) in order to achieve the desired (power) values at the interface to the Transmission System.



## 8 VERIFICATION OF THE ELECTRICAL CHARACTERISTICS

The following information of the Wind Farm and of the wind turbine generators is necessary before the permission for the grid connection can be given:

- 1) Layout of the Wind Farm (electrical layout, cabling, location of wind turbine generators)
- 2) Technical data of the Wind Farm
- 3) Technical data of the wind turbine generators
- 4) Technical data of the transformers
- 5) Black box model in ultimately PSSE package or any other software package available to EETC in future to carry the same function
- 6) White box model in ultimately PSSE package or any other software package available to EETC in future to carry the same function
  
- 7) Layout of the grid connection (switchgear)
- 8) A detailed calculation of the fault infeed has to be provided to specify 3-phase short circuit infeed from the system and how the value has been determined.
- 9) Protection concept
- 10) Time schedule
- 11) Measurement report of an accredited company (accredited according to IEC 17025 for the respective measurements of electrical characteristics of wind turbine generators), giving the electrical characteristics of the wind turbine type according to IEC61400-21 [1]. The complete measurements are required on corresponding wind turbine prototypes from accredited companies.
- 12) Evidence of agreed properties / requirements
- 13) Evidence that the Wind Farm behaves on the Grid in accordance with the Grid Code.

During the commissioning test at least the following will be checked:

- 1) Commissioning program and schedule
- 2) Plant documentation (construction plans, circuit diagrams,..)
- 3) Set-point control of active power
- 4) Set-point control of reactive power
- 5) Disconnection
- 6) Start-up after grid losses
- 7) Grid protection.

## 9 REFERENCES

- [1] IEC 61400-21: Wind turbine generator systems – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines standard. Edition 2.0 2008-08).
- [2] IEEE Std 519-1992. IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.

[3] IEC/TR 61000-3-7 ed2.0 . Electromagnetic compatibility (EMC) - Part 3-7: Limits - Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems