Functional Design Specification for Grid Interface Control

La Flor Wind Farm

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History of this Document

Version no.	Date	Description of changes	Technical approver
00	2019-03-18	Document created	ALILE
01	2019-04-24	Edition changes	ALILE
02	2019-05-16	Edition changes	ALILE
03	2019-06-18	Final grid data added	ALILE
04	2019-11-04	Revision of POM and POC definition	ALILE

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1 Introduction

1.1 Purpose

The La Flor Wind Farm (the WPP) consists of 9 units of V136-3.6 MW, 50Hz, Gridstreamer™. The WPP’s Maximum Export Capacity (MEC) is 32.4 MW.

The purpose of this document is to describe the functionality and design of the control system for the grid interface of the WPP.

1.2 References

Where cross-references are made to other documents, these are noted [x] in the text where [x] refers to the number in the below list.

No.	Document number	Document
1	0058-1667	VestasOnline® Power Plant Controller, Mk 4 General Specification
2	0008-1534	Electrical Wind Power Plant Performance based on Power Plant Controller
3		Signal List PPC-RTU
4		Signal List RTU-TSO

Table 1-1: Document references.

1.3 List of Abbreviations

The following abbreviations are used in this document:

Abbreviation	Spelled-out form/explanation
CB	Circuit Breaker
BOP	Balance of Plant
FAT	Factory Acceptance Test
FSM	Frequency-sensitive mode
HMI	Human-Machine Interface
LFSM	Limited frequency sensitivity mode
LVRT	Low Voltage Ride Through
MSC	Mechanically Switched Capacitor
OLTC	On Load Tap Changer (main transformer)
PF	Power Factor
POC	Point of Connection
PoM	Point of Measurement
PPC	VestasOnline® Power Plant Controller
pu	Per unit
RTU	Remote Telemetric Unit – power control interface
SAT	Site Acceptance Test
SCADA	Supervisory Control and Data Acquisition
STATCOM	Static Compensator (VAr – compensator)
TBD	To be defined
TSO	Transmission system operator, or by default the operator of the electrical system to which the WPP is connecting
UPF	Unity Power Factor
VOB	VestasOnline® Business
WPP	Wind Power Plant, i.e. the Reynosa Wind Farm
WTG	Wind Turbine

Table 1-2: Abbreviations.

2 Configuration of the Plant

2.1 Basic information

WPP basic information:

Vrated HV	66kV
Vrated MV	23kV
Prated	32.4MW
WTG type	V136-3.45/3.6MW 50Hz
Number of WTGs	9

2.2 Main circuit configuration

The WTGs are connected in two 23kV feeders. The production is then exported through a 23kV overhead line into Nahuelbuta Frontel 23/66kV substation.

The legal POC is defined at 23kV side of the transformer in Nahuelbuta Frontel 23/66kV substation, where the fiscal energy metering is installed.

2.3 Control setup

The WPP will perform the regulation at 66kV side of the transformer in Nahuelbuta Frontel 23/66kV substation, therefore, from a regulation point of view, POC is defined as 66kV side of the transformer in Nahuelbuta Frontel 23/66kV substation.

The POM is located at the same point where regulation needs to be performed.

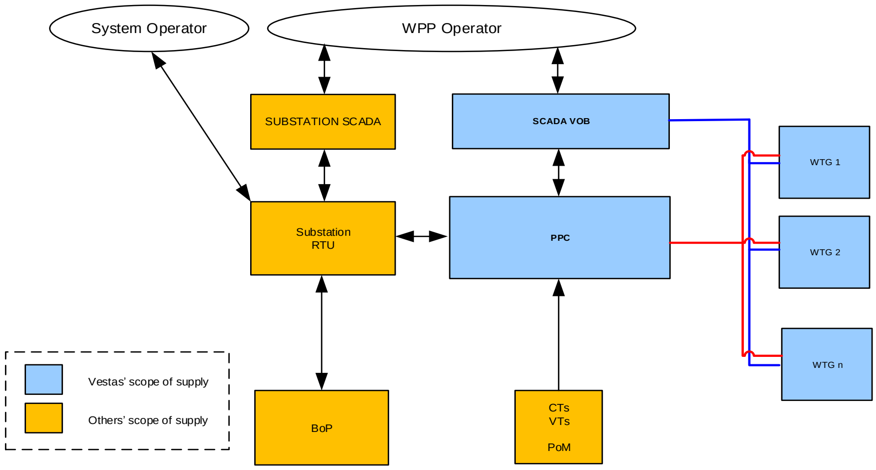

Figure 2-1: Control architecture.

The PPC cabinet, the VOB Server and the SCADA HMI will be installed in the windfarm control building.

Power Meter Name	Power meter identification (name or drawing id)	CT ratio	VT ratio
PowerMeterSourceID 0	POM	400/1	69.000 / √3 – 115 / √3 V

3 Grid interface control functionality

The WPP will incorporate the following control functions, which will be implemented on the PPC.

- Reactive power control functions:
  - ✓ Voltage control
  - ✓ Reactive power control
  - ✓ Power factor control

- Active power control functions:
  - ✓ Active power control 0-100%
  - ✓ Active power ramp rate
  - ✓ Frequency response

A control signal interface in DNP3 will be implemented between the Vestas PPC and the Substation RTU, to fulfil the control signal requirements towards the TSO in terms of WTG and PPC-related control signals. It must be noted that the interface with the TSO will be implemented in the Substation RTU and is outside of Vestas' scope.

3.1 Master/Slave

The WPP will receive high level commands from the WPP operator, or from TSO through the Substation RTU, according to the signal list defined in [3].

The PPC will act as the control master to implement the received setpoints.

For active and reactive power regulation, the reference will be implemented by dispatching the WTGs.

3.2 Reactive power control functions

3.2.1 Reactive power control modes

The WPP will be able to operate in 3 different modes for the reactive power control:

- Voltage control mode, with the WPP controlling the Q injection at the POC to implement the required voltage reference at POC.
- Power factor control mode, with the WPP controlling Q injection at the POC based on a power factor reference.
- Reactive power control mode, with the WPP implementing a reactive power reference for the injection at the POC.

The operation mode of the reactive power control response and the references will be defined by the system operator and received by the PPC through the Substation RTU, which runs the control interface towards the system operator.

In the Vestas SCADA HMI, the WPP operator can visualise and change the commands from the system operator. The control characteristic for the voltage control will be defined by the WPP operator in Vestas SCADA HMI

The PPC will signal the status of the actual reactive power control status and operation points to the Substation RTU in order to have that information relayed to the system operator in the communication interface of the WPP.

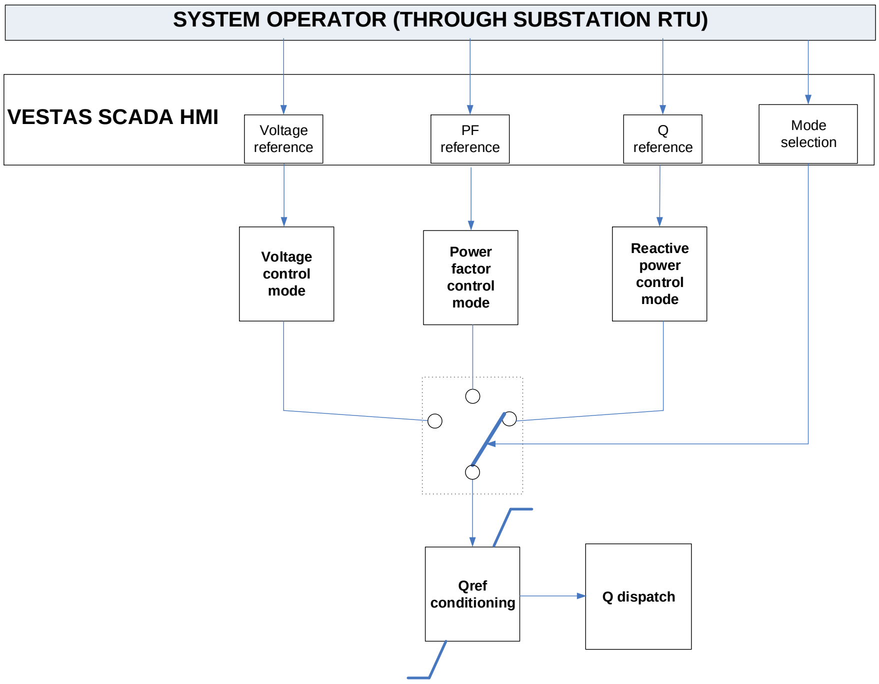

Figure 3-1: Reactive power control

The default reactive power control mode for the WPP will be Voltage control.

3.2.2 Signal lists for reactive power control

The control signals related to active power control exchanged between the WPP and the TSO, managed by the Substation RTU, are defined in [4].

The control signals related to reactive power control exchanged between Vestas' PPC and the Substation RTU are defined in [3].

3.2.3 Reactive power reference conditioning

The reactive power reference will be capped by the following absolute and dynamic reference limits.

PF limit capacitive	0.83
PF limit inductive	0.83
Q limit capacitive	10.7MVAr
Q limit inductive	10.7 MVAr
Q_{ref} ramp rate limit	0.1 pu/s

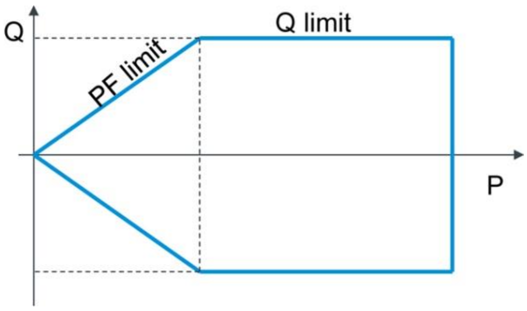

Figure 3-2: Reactive power reference absolute limits

3.2.4 Voltage Control Mode

The voltage control loop will operate in PI voltage control mode, where the WPP will adjust its Q injection / absorption in the POC by means of a PI control algorithm that aims to reduce to zero the voltage error between the measured voltage at POC and the defined voltage reference.

It must be noted that this control mode does not ensure the defined voltage reference can be achieved. The WPP will saturate its reactive power control action at the defined limits

Type of voltage control	PI
SCR	6
X/R	3

3.2.5 Reactive power control dynamic performance

The reactive power control action that results from the reactive power control will be tuned to perform within the requirements defined in the figure below to step changes in the reference or step disturbances.

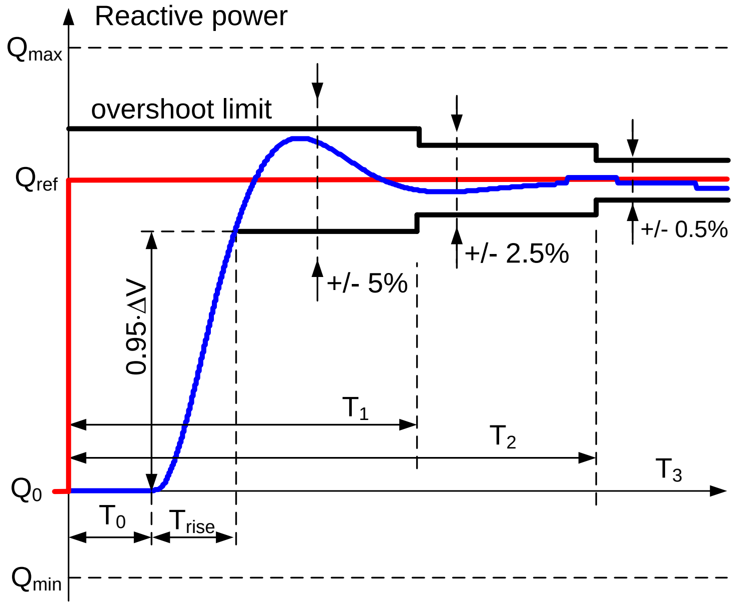

Figure 3-3: Reactive power control dynamic performance.

T_0	typical performance around 0.2s deadtime
T_{RISE}	3s
T_2	<5s

3.2.6 Reactive power control during no wind conditions

When WPP active power production at POI falls below 0kW, the reactive power control will change to PF control and limit the exchange to 0kVAr.

3.3 Active Power control

3.3.1 Active power control modes

The WPP will be able to operate in 3 different modes for the active power control.

- **No frequency response mode**

  While in this operation mode, the following constraint functions can be commanded by the system operator or WPP operator:

  - ▷ Absolute Production Constraint (Curtailment).
  - ▷ Power Gradient Constraint (Power Gradient). Applied to active power reference changes.

- **Limited frequency sensitivity mode - Overfrequency (LFSM-O)**

  This mode provides response from the WPP to overfrequency events as per a characteristic defined by the system operator and implemented in the PPC.

  While in this operation mode, the following constraint functions can be commanded by the system operator or WPP operator:

  - ▷ Absolute Production Constraint (Curtailment).
  - ▷ Power Gradient Constraint (Power Gradient). Applied to active power reference changes.

- **Limited frequency sensitivity mode – Overfrequency + Underfrequency (LFSM-O-U)**

  This mode provides response from the WPP to overfrequency and underfrequency events as per a characteristic defined by the system operator and implemented in the PPC.

  While in this mode, the WPP implements a Pdelta regulation band – in terms of a percentage of the available active power - following the commanded value defined by the system operator or the WPP operator. It must be noted that in this mode, the WPP cannot respond to Absolute Production Constraint commands.

The operation mode of the frequency response, and the references to be implemented, will be defined by the system operator, through the WPP control interface in the Substation RTU, or by the WPP operator in the Vestas SCADA HMI.

The default operation mode will be LFSM-O.

The control characteristics will be defined by the WPP operator in the Vestas SCADA HMI.

The PPC will signal the status of the frequency response to the Substation RTU in order to have that information relayed to the system operator in the communication interface of the WPP.

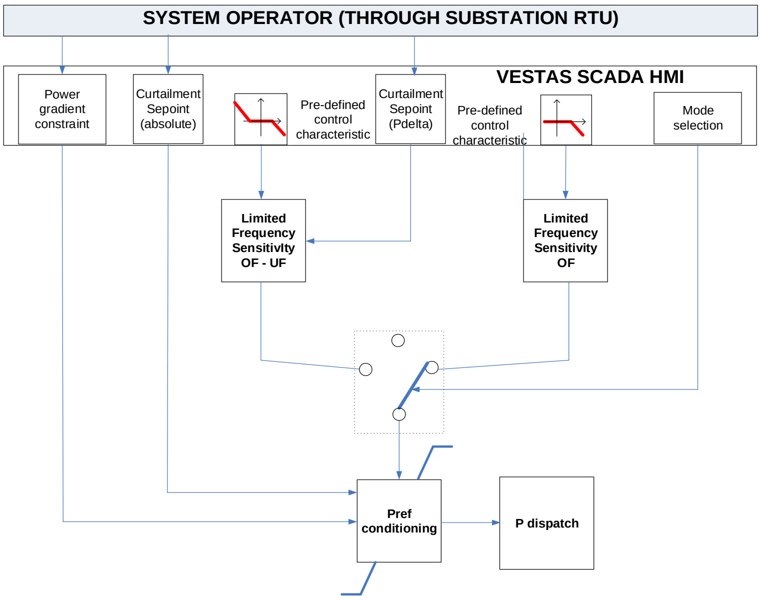

Figure 3-4: Active power control

3.3.2 Signal lists for active power control

The control signals related to active power control exchanged between the WPP and the TSO, managed by the Substation RTU, are defined in [4].

The control signals related to active power control exchanged between Vestas' PPC and the Substation RTU, are defined in [3].

3.3.3 Active power output ramp rate limitation

The WPP will limit the rate of change of the active power output at POC, as per the limit reference defined by the system operator, as received by the PPC through the WPP control interface in the Substation RTU, or by the WPP operator in the Vestas SCADA HMI directly.

This limit can be set between 1 and 20% of rated power per minute.

It must be noted that active power ramp limits will not be able to control the rate of change of the active power output of the WPP in case of decreasing wind speed, disconnection of WTGs due to cut-out wind speed or disconnection of WTGs due to switching actuations in the main circuit of the WPP.

By default, the following settings will be used

Active power output ramp limit	6 480 kW / min (20%/min)

3.3.4 Active power reference conditioning

The reference to be dispatched to the WTGs will be the minimum of the different references issued by frequency response, high wind curtailment, external curtailment or Vestas SCADA HMI reference.

P_{ref} maximum	32.4 MW
Pramp limit (internal)	0.05pu/s

An internal default Pramp limit is defined that will be seried with power gradient constraint references set by the system operator. It is expected that the defined internal limit is faster than the range of values that will be requested by the system operator, therefore it will not affect the ability of the WPP to implement the gradients required by the system operator.

It must be noted that active power ramp limits will not be able to control the rate of change of the active power output of the WPP in case of decreasing wind speed, disconnection of WTGs due to cut-out wind speed or disconnection of WTGs due to switching actuations in the main circuit of the WPP.

3.3.5 Technical minimum production

For the individual WTGs, there is a technical minimum level active power reduction upon external command. This minimum level must be respected to protect the WTGs from excessive mechanical loads. If the external active power reference for an individual WTG goes below 10% its rated power, this WTG will be paused.

For the regulation of active power output of the WPP at POC, the PPC will decide for a setpoint if pausing a number of individual WTGs is needed in order to achieve the reference. Nevertheless, the minimum setpoint that can be implemented will be the minimum Pref of a single WTG.

3.3.6 LFSM-O (Limited frequency sensitivity mode – Overfrequency).

The LFSM-O mode will implement a control characteristic as described below.

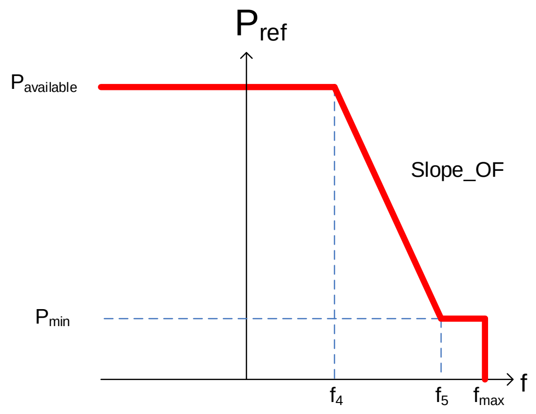

Figure 3-5: LFSM-O response characteristic

f_4	50.2 Hz
f_{max}	52Hz
f_5	51.5 Hz
P_{min}	28.5% of Pavailable
SLOPE_OF	3.64%
P ramp rate limit (default)	0.025pu/s

3.3.7 LFSM-O-U (Limited frequency sensitivity mode – Overfrequency + Underfrequency).

The LFSM-O-U mode will implement a control characteristic as described below.

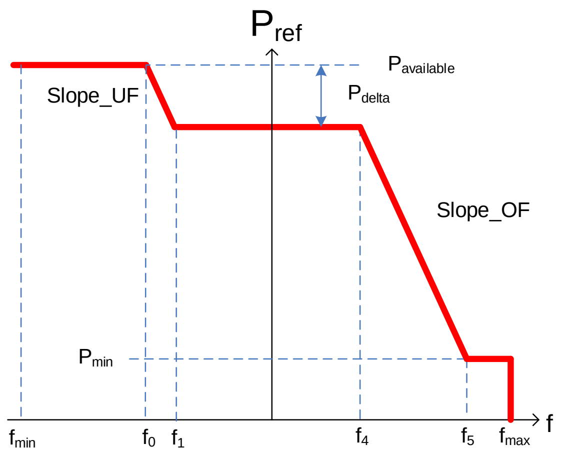

Figure 3-6: LFSM-O-U response characteristic

f_{min}	48Hz
f_0	(f_1 – (P_{delta} [%] x SLOPE_UF / 100 / 100 x 50)) Hz
f_1	49.8 Hz
SLOPE_UF	3.64%
P_{delta}	Defined by WPP Operator or TSO (default: 3%)
f_4	50.2 Hz
f_{max}	52Hz
f_5	51.5 Hz
P_{min}	((100 – 100 x (f_5 - f_4) / 50 x 100 / SLOPE_OF) %) - P_{delta}) %
SLOPE_OF	3.64%
P ramp rate limit (default)	0.025pu/s

4 Fault Ride-Through (FRT) control

The following strategy will be adopted by the WPP control systems to respond to LVRT or HVRT events:

- The PPC will freeze the regulation loops when voltage at POM is detected to be outside of the normal operation range

V_{max}	1.1pu
V_{min}	0.9pu

- During the freeze control state, the PPC will dispatch references to WTGs based on feed-forward mode (value measured at PoM is dispatched as reference to the WTGs)
- The WTGs will respond to the HVRT or LVRT following the local WTG FRT Iq-V control characteristic, using the voltage measured in their LV terminals to define the entry/exit and current injection level. During local FRT control mode in the WTGs, the references sent by the PPC are not implemented in the WTGs as the local control goes into FRT mode and the WTG is controlled as an Iq source following the voltage in the WTG terminals.

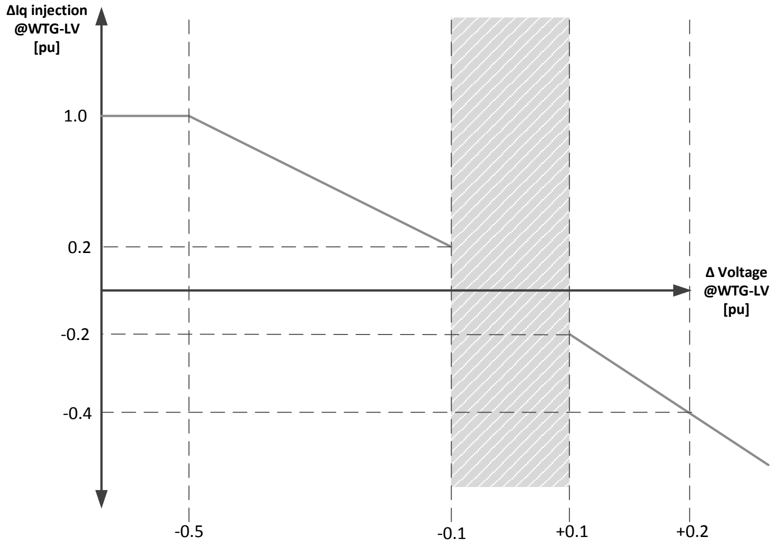

Figure 4-1: WTG Iq-V local control characteristic

- Once voltage at PoM has recovered to normal levels, the PPC will wait for the WTGs to exit the FRT control model to start sending reference and bringing the WPP back to normal operation.

5 Fall-back scenarios

The following fall-back scenarios are defined for the WPP control system to respond to abnormal operation in its components or communication:

- If the WTGs loose communication to the PPC, they will keep the last healthy setpoints received for a certain wait time, and if communication was not restored they will revert to:
    - Producing available active power
    - UPF operation at their LV terminals
- If the PPC loses communication to the Substation RTU, the WPP will revert to default operation modes:
    - Voltage control mode, with the default settings.
    - Frequency response LFSM-O, keeping the last healthy external curtailment reference and ramp rate limit received.
- If the PPC loses communication to the POM equipment, the WPP will revert to the following operation mode:
    - For the active power regulation: The loop will substitute the missing POM feedback with the sum of turbine production.
    - For the reactive power regulation: The loop will freeze and not evaluate reference changes or update set points to turbines. The loop will resume normal operation when communication to the power meter is re-established.