Primary Frequency Regulation Requirement of South Africa Grid Code and its DIgSILENT Simulation

Jingchun Chu[1], Ling Yuan[1], Haining Pan[1,*] and Jianming Hou[1]

[1]Technical Centre, State Key Laboratory of Wind Power Equipment and Control, Guodian United Power Technology Company LTD., Beijing, China

Abstract. Wind power is a kind of renewable energy with unexpected and unfriendly characteristics, so different countries have their own grid code to restrain wind power generation to an acceptable performance. In South Africa, before a Wind Power Plant (WPP) is connected to the grid, WPP's performance must be pre-evaluated according to the requirements of the Grid Code, which is compulsory for any new WPP of South Africa. This paper firstly introduced the primary frequency regulation requirement for WPP evaluation in South Africa, then explained how the WPP, Power Plant Controller (PPC) and wind turbine generators (WTGs) are modelled and manipulated. Secondly, DIgSILENT model of a wind energy project in South Africa is built, and its PPC controller is initialized for simulating primary frequency response. Thirdly, simulation is executed to follow the pre-defined grid dispatch constructions, and the simulation results are compared with the on-site test records to evaluate the consistency with the grid code. The plant's overall precision and response speed for validation test was well performed and compliant with grid code.

1 Introduction

The increasing penetration of renewable generation plants formed by a large number of individual generating units poses a challenge to system operators, in terms of technical singularities, connection process and plant modelling management. The power balance in the electrical network is interrelated to the network frequency via all synchronous generators connected to it. The ability of a system to maintain its frequency within a certain tolerance band is called frequency stability.

In order to maintain system frequency stability in a network with an increasing share of wind power, wind turbines will have to take on more and more tasks of conventional power plants related to frequency control [1, 2]. A gradual research [3] of more stringent requirements by system operators in regard to the integration of wind power plants into network frequency control is developed in the past decade.

Grid codes specify the electrical performance that generation assets must comply with in order to obtain the required approval for its connection to a grid. Demonstrating grid code compliance and achieving a grid connection agreement are, therefore, essential milestones in the development of a power plant project.

In order to cope with these issues, specific compliance procedures based on testing and simulation have already been established for Renewable Energy Sources (RES). The present paper introduces current procedures and practices on grid code compliance verification for renewable power generation.

This work firstly presents a review of South Africa Grid Codes regarding the tasks of frequency response evaluation related to participation in frequency control. Secondly, DIgSILENT model of a wind energy project in South Africa is built, and then its PPC is initialized for simulating primary frequency response. Thirdly, simulation is executed to follow the pre-defined grid dispatch constructions, and the simulation results are compared with the on-site test records to evaluate the consistency with the grid code.

2 Power-frequency response curve for in South Africa

2.1 requirements in grid code

Power-frequency response is crucial for the successful integration of wind power plants into the grid.

- RPPs shall be designed to be capable to provide power-frequency response as illustrated in Figure 1.
- Except for the mandatory high frequency response (above 50.5 Hz), the RPP shall not perform any frequency response function without having entered into a specific agreement with the SO.
- It shall be possible to set the frequency response control function for all frequency points shown in Figure 7. It shall be possible to set the frequencies f_{min}, f_{max}, as well as f_1 to f_6 to any value in the range of 47 - 52 Hz with a minimum accuracy of 10 mHz.
- The purpose of frequency f_1 to f_4 is to form a dead band and a control band for RPPs contracted for primary

---

[*] Corresponding author: 12048938@chnenergy.com.cn

frequency response. The purpose of frequency points f_4 to f_6 is to supply mandatory critical power/frequency response.

- The RPP shall be equipped with the frequency control droop settings as illustrated in figure 7. Each droop setting shall be adjustable between 0% and 10%. The actual droop setting shall be as agreed with the SO.
- The SO shall decide and advise the RPP generator (directly or through its agent) on the droop settings required to perform control between the various frequency points.
- If the active power from the RPP is regulated downward below the unit's design limit P_{min}, shutting-down of individual RPP units is allowed.
- The RPP (with the exception of RPP-PV) shall be designed with the capability of providing a P_{Delta} of not less than 3% of $P_{available}$. P_{Delta} is the amount of active power by which the available active power has been reduced in order to provide reserves for frequency stabilisation.
- It shall be possible to activate and deactivate the frequency response control function in the interval from f_{min} to f_{max}.
- If the frequency control setpoint (P_{Delta}) is to be changed, such change shall be commenced within two seconds and completed no later than 10 seconds after receipt of an order to change the setpoint.
- The accuracy of the control performed (i.e. change in active power output) and of the setpoint shall not deviate by more than ±2% of the set point value or by ±0.5% of the rated power, depending on which yields the highest tolerance.

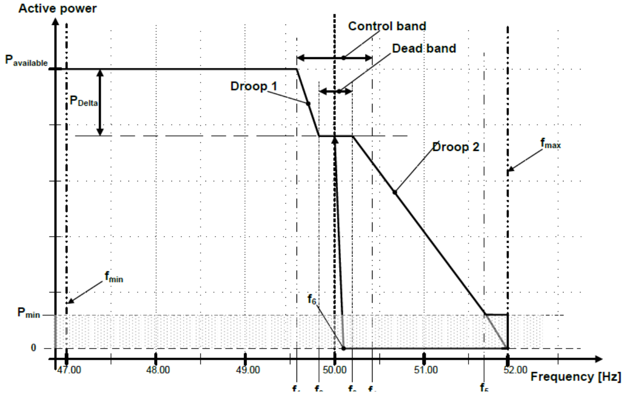


Fig. 1. Frequency response requirement for RPPs of category C.

- The default settings for fmin, f_{max}, f_4, f_5 and f_6 shall be as shown in Table 3, unless otherwise agreed upon between the SO and the RPP generator. Settings for f_1, f_2 and f_3 shallbe as agreed with the SO.

Table 1. Frequency default settings.

Parameter	Magnitude (Hz)
f_{min}	47
f_{max}	52
f_1	As agreed with SO
f_2	As agreed with SO
f_3	As agreed with SO
f_4	50.5
f_5	51.5
f_6	50.2

- The SO or its agent shall give the RPP generator a minimum of 2 weeks if changes to any of the frequency response parameters (i.e. f_1 to f_6) are required. The RPP generator shall confirm with the SO or its agent that requested changes have been implemented within two weeks of receiving the SO's request.

2.2 Grid code compliance verification

The verification should include the revision of documentation (including technical data and models), the verification of the requested capabilities of the facility by practical tests and simulation studies and, finally, the validation of the model performance based on actual measurements. Grid code compliance verification has a double objective. Plant owners are responsible for demonstrating compliance of the grid code to the relevant network operator, and network operators have to assess the compliance in order to ensure that the new plant will not adversely affect the secure operation of the power system. A grid code should be complemented by a good verification plan, in order to avoid misinterpretations of the requirements

3 Overview of wind farm

The objective Wind Farm lies in north of South Africa, which consists of a total of 67 UPC UP86 Wind Turbine Generators (WTG) with a combined generation capacity of 100.5 MW. Power will be generated at 690 V at each WTG and collected at 33 kV through 6 dedicated collector circuits consisting of MV overhead lines and power cables. Power will be exported to the National Grid at 132 kV.

Power will be generated at 690 V and stepped-up to 33 kV through dedicated 1800 kVA transformers. The 33 kV collector network will be split into 6 collector circuits consisting of MV overhead lines and MV cables. The overhead lines will consist of 33 kV Kingbird, Chicadee, Hare and Mink ACSR conductors. Cross-Linked Polyethene (XLPE) copper cables rated 19/33 kV will be installed between the 33 kV terminal towers and the 1800 kVA 0.69/33 kV step-up transformers. Power will be exported at 132 kV through 2 33/132 kV 60 MVA power transformers and a dedicated ~ 18 km 132 kV overhead power line connecting Phiri Switching Station to the Hydra MTS. The 132 kV overhead line is excluded from the DIgSILENT PowerFactory model because the study requirements focus on the POC and the PCC which is located at the De Aar Maanhaarberg Substation.

The Maximum Export Capacity (MEC) of De Aar Maanhaarberg Wind Farm is 96.48 MW at the POC. The Point of Connection (POC) is at the terminals of the Eskom 132 kV line isolators at the Phiri Substation. The Point of Common Coupling (PCC) is at the 132 kV busbar at the Eskom Phiri Substation in accordance with the DCUOSA Annexure C.

The overall Wind Farm is shown below in Figure 2.

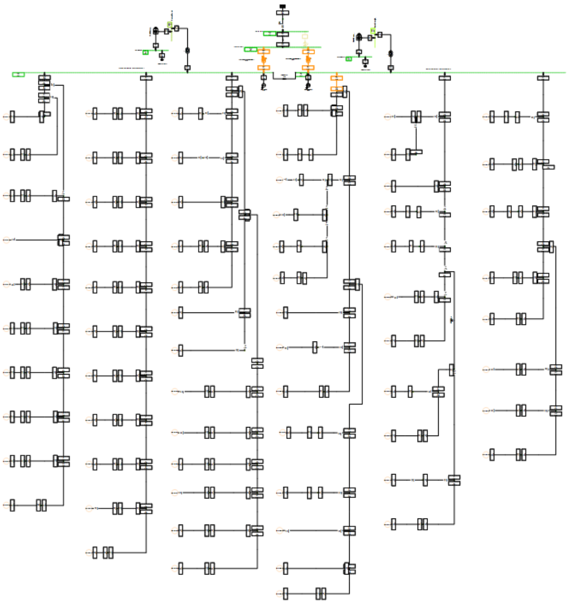


Fig. 2. Single-line diagram of the objective wind farm model.

4 Model and interfaces of the wind farm

The mostly used and manipulated are the interfaces of PPC, WTG and STATOM. So in the next chapter, their interfaces and structures will be introduced.

4.1 Introduction to PPC model

In order to preform simulation of LVRT and HVRT cases, model of wind park controller that is able to regulate active and reactive power at point of common coupling was developed. Model is developed using DSL language with DSL block name of" PPC Execute". "PPC_Execute" aims to stabilize active and reactive power at point of common coupling according to set points values before 0 time point using PI control approach.

4.1.1 Accessing PPC model

PPC is modelled as the composite model in DIgSILENT. Parameters for PPC controller are depicted in Table.2. Slot names and net elements of PPC controller are:

- PPC_Execute: contains the PPC controller.
- Q measurement: contains the P&Q measurement at POC.
- Voltage measurement: contains the voltage measure-ment at POC.

Parameters of PPC controller are listed in Table 2.

Table 2. Parameters for PPC controller

Parameter	Parameter description
InitPI_POut	Initial value of active power set points to wind turbines.
InitPI_QOut	Initial value of reactive power set point to wind turbines.
P_Kp	Active power PI Controller proportional gain.
P_Ki	Active power PI controller integral gain.
Q_Kp	Reactive power PI Controller proportional gain.
Q_Ki	Reactive power PI controller integral gain.
p_set_pu	Wind park active power set point in p.u. relative to nominal apparent power
P_set_pu	Reactive power set point in p.u. relative to nominal apparent power

4.1.2 Inputs of PPC_execute model

Inputs of PPC controller "PPC_Execute" is shown below in Table 3.

Table 3. Inputs of PPC execute model

Variable	Description
fref	Frequency measurements at point of common coupling(PCC)
u	Voltage measurement at PCC
p	Active power measurement at PCC in p.u.
q	Reactive power measurement at PCC in p.u.

4.1.3 Outputs of PPC_Execute Model

Outputs of PPC controller is shown below in Table 4.

Table 4. Outputs of PPC execute model

Variable	Description
Pref	Active power set point from wind park controller to wind turbines in p.u.
Qref	Reactive power set point from WPC to wind turbines and STATCOMs in p.u.
Stop	Stop signal from wind park controller to wind turbines

4.2 Introduction to WTG model

Wind turbine generator is the fundamental unit to produce active power and reactive power, so it is needed to follow the command of PPC at normal condition and produce reactive current support on its own during VRT process. For the sake of voltage dips of grid system, WTG need also the ability of voltage ride through.

4.2.1 Accessing WTG model

WTG is modelled as the composite model in DIgSILENT. Slot name and its Net Elements are:

- WT_DSL: contains the WTG controller.
- Wind Turbine: contains the generator model of WTG.
- PQmea: contains the P&Q measurement of WTG.
- Vmeas: contains the voltage measurement at terminal of WTG.

Parameters of WTG controller are listed in Table 5.

Table 5. Parameters for WTG controller

Parameter	Parameter description
P_base	Rated active power of wind turbine in kW
Q_max	Maximum reactive power of wind turbine in normal condition in kVar
MinFrequency	Minimum Frequency limit in p.u.
TFtripMin	Trip time delay for MinFrequency
MaxFrequency	Maximum Frequency limit in p.u.
TFtripMax	Trip time delay for MaxFrequency
LowVoltage1	Voltage set 1 for low voltage ride through in p.u.
TVtripLow1	Trip time delay for LowVoltage1
LowVoltage2	Voltage set 2 for low voltage ride through in p.u.
TVtripLow2	Trip time delay for LowVoltage2
LowVoltage3	Voltage set 3 for low voltage ride through in p.u.
TVtripLow3	Trip time delay for LowVoltage3
LowVoltage4	Voltage set 4 for low voltage ride through in p.u.
TVtripLow4	Trip time delay for LowVoltage4
HigVoltage1	Voltage set 1 for high voltage ride through in p.u.
TVtripHig1	Trip time delay for HigVoltage1
HigVoltage2	Voltage set 2 for high voltage ride through in p.u.
TVtripHig2	Trip time delay for HigVoltage2
model_id	Id for model, set to constant 1
Wind_turbine_id	Id of turbines

4.2.2 Inputs of WTG_DSL

Inputs of WTG controller is shown below in Table 6.

Table 6. Inputs of WTG controller

Variable	Description
P_m	Active power measured at terminal of wind turbine generator in p.u.
Q_m	Reactive power measured at terminal of wind turbine generator in p.u.
fref	Frequency measurements at terminal of wind turbine generator in p.u.
u	Voltage measurement at terminal of wind turbine generator in p.u.
PPC_P_set	P set command from PPC controller
PPC_Q_set	Q set command from PPC controller
PPC_stop	Not used now

4.2.3 Outputs of WTG_DSL

Outputs of WTG controller "WTG_DSL" is shown below in Table 7.

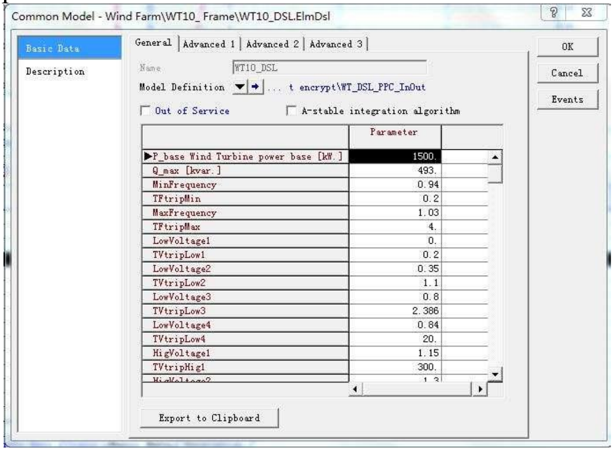
Table 7. Outputs of WTG controller

Variable	Description
id_ref	Active current set point for wind turbine generator in p.u.
iq_ref	Reactive current set point for wind turbine generator in p.u.

5 Simulation setup and results

5.1 Simulation setup

Because WTG's controller block and PPC's controller block are both modeled inside DIgSILENT by using DSL language, interfaces are designed for users to access them. The interface dialog (Figure 3) shows the parameters for WTG controller.



Name: WT10_DSL
Model Definition: ... t encrypt\WT_DSL_PPC_InOut
☐ Out of Service
☐ A-stable integration algorithm

	Parameter
P_base Wind Turbine power base [kW.]	1500.
Q_max [kvar.]	493.
MinFrequency	0.94
TFtripMin	0.2
MaxFrequency	1.03
TFtripMax	4.
LowVoltage1	0.
TVtripLow1	0.2
LowVoltage2	0.35
TVtripLow2	1.1
LowVoltage3	0.8
TVtripLow3	2.386
LowVoltage4	0.84
TVtripLow4	20.
HigVoltage1	1.15
TVtripHig1	300.

Fig. 3. Common Model for WTG controller.

Parameter settings for WTG controller are depicted in Figure 5.

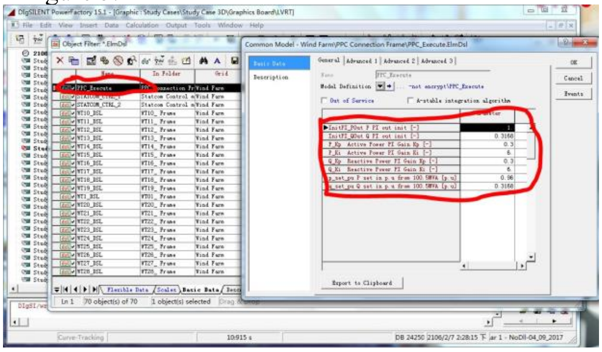


Fig. 4. Common Model for PPC controller

Parametres undefined in Table 1 are set as Table 8, which are accepted by the grid operator of South Africa.

Table 8. Frequency default settings.

Parameter	Magnitude (Hz)
f_1	47.5
f_2	49.8
f_3	50.2

After the expected active power is desided by Fig.1 according to a given measured frequency, the total active power performance is regulated by PI controller in PPC. The structure of active power regulation is shown in Fig.5. PI_Out is sent to the dispatching controller as the actual active power, which is dispatch to each WTG by avarage.

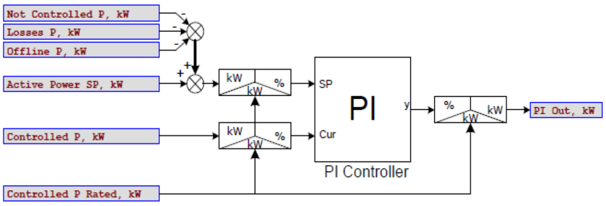


Fig.5. Structure of active power regulation

5.2 Simulation results and verification

For frequency Control with constant value, the on-site test was performed at POC level. The available power for this test was 85.89MW. For the active power control test, the plant was given active power set points from 10% to maxim available power gradually. It managed to keep the active power constant. The onsite test results is shown in Fig. 6 as the blue lines. The simulation results is shown as the green one. Set points are shown as the red one. As we see, the active power is stabilized precisely around the set points throughout the testing process.

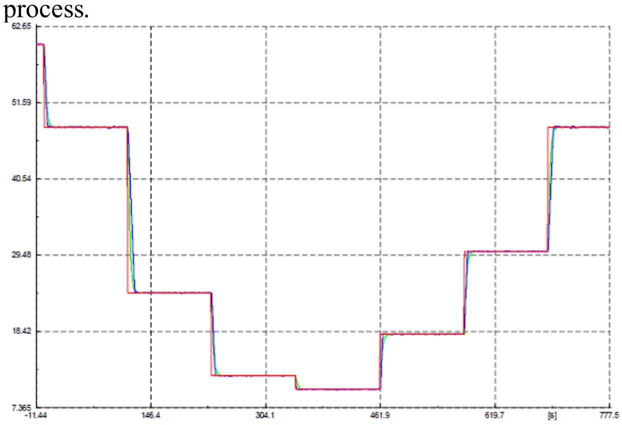


Fig.6. Test and simulation results for active power control.

For frequency test, the plant was given frequency set points from 50Hz-48Hz.According to GCCRPP [4], compliance testing is defined as the process of verification that power generating facilities comply with specifications and requirements provided by this grid code.

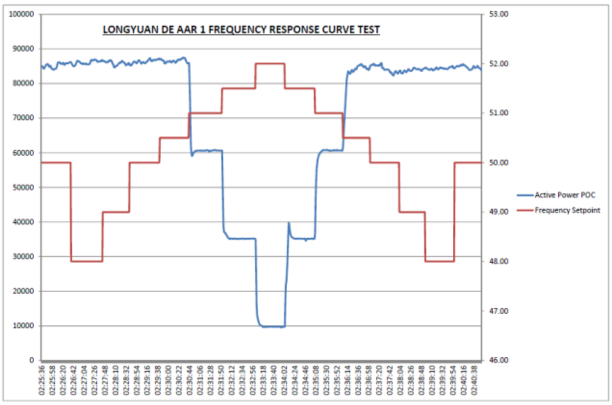


Fig.7. Test Result for frequency response.

We can see in Fig.7 that accuracy of the frequency-power control performed (i.e. change in active power output) did not deviate by more than ±2% of the set point value or by ±0.5% of the rated power.

6 Conclusions

For over-frequency tests, the frequency was increased from 50Hz-52Hz. Combining the fast communication technology, including hardware updating and protocol optimization, the plant responded well to the over-frequency setpoints and reduced the active power as per the frequency response curve. The communication technology development in this wind energy project will be systematically introduced later.

Acknowledgement

This work is supported by China National Energy Company under the project, Load shedding and Power Consumption of Large Smart Turbine (GJNY-18-10), and the project, Research and Application of Key Technologies for Distributed Wind Turbine Generator (GJNY-19-32).

References

1. ENTSO-E. ENTSO-E network code for requirements for grid connection applicable to all generators, available online: (https://www.entsoe.eu/). (2013)
2. EirGrid and System Operator for Northern Ireland (SONI). All island TSO facilitation of renewables studies, available online: (http://www.eirgrid.com). (2013)
3. M. Mohsenia, M. M. Islamb, Review of international grid codes for wind power integration-Diversity, technology and a case for global standard, Renewable and Sustainable Energy Reviews. **16**, 3876 (2012)
4. Grid connection code for renewable power plants connected to the electricity transmission system or the distribution system in South Africa. NERSA, (2016)