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

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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, DlgSILENT 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, DlgSILENT 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 \( f_{\text{min}} \), \( f_{\text{max}} \) 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
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 \( P_{\text{min}} \), 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 \( P_{\Delta \text{eta}} \) of not less than 3% of \( P_{\text{available}} \). \( P_{\Delta \text{eta}} \) 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 \( f_{\text{min}} \) to \( f_{\text{max}} \).
- If the frequency control setpoint \( (P_{\Delta \text{eta}}) \) 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.

### Table 1. Frequency default settings.

| Parameter | Magnitude (Hz) |
|-----------|----------------|
| \( f_{\text{min}} \) | 47 |
| \( f_{\text{max}} \) | 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. \( f_4 \) 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 Polyethylene (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 MV A 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 DiSILENT 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 DCUUSA Annexure C.

The overall Wind Farm is shown below in Figure 2.
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 perform 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 DlgSILENT. 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 measurement at POC.

Parameters of PPC controller are listed in Table 2.

| 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. |

4.1.2 Inputs of PPC_execute model

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

| 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.

| 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 DlgSILENT. 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.
4.2.2 Inputs of WTG_DSL

Inputs of WTG controller is shown below in Table 6.

| 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.

| 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 DlgSILENT by using DSL language, interfaces are designed for users to access them. The interface dialog (Figure 3) shows the parameters for WTG controller.

Parameter settings for WTG controller are depicted in Figure 5.

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

| Parameter | Magnitude (Hz) |
|-----------|---------------|
| f1        | 47.5          |
| f2        | 49.8          |
| f3        | 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 average.

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.

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.

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