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Analysis of Grid Code Requirements for Wind Power Dynamic Model

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Abstract

Renewable energy and energy storage system are a hot topic today since the global warming is related to the burning of fossil fuels. Renewable generations using wind, solar and wave sources are integrated into power system for securing economic feasibility. However, grid-connected wind power having its natural variability greatly may affect stability of power system, and TSO (Transmission System Operator) and ISO (Independent System Operator) have developed grid code for wind power. Especially, technical requirements for testing and simulation are specified in grid code because GCC (Grid Code Compatibility) is ascertained through onsite testing and computer simulation. Therefore, the simulation model requirements should be understood clearly from the early stage of project, and the exact models and reports can be delivered to TSO and certification body on time. Namely, wind turbine manufacturer should deliver its dynamic models, model validation report and test report, on the other hand, wind power plant owner should deliver its dynamic models and commissioning report. The accurate understanding of different simulation model requirements presented from various national grid code avoids simulation modeling error.

Keywords*: Wind Power, Grid Code (GC), Grid Connection Compatibility (GCC), Dynamic Stability, Simulation Model Requirements*

1. Introduction

Despite policy support decline and uncertainty, renewable energy markets continue to grow. Global new investment in renewable power and fuels is $ 214 billion in 2013 and worldwide cumulative installed wind power capacity to 2013 is 326 GW (318 GW onshore and 8 GW offshore) [1]. The connecting large scale wind power to power system is common practice because of scale economies. However, unfortunately, the increase of penetration level may negatively affect stability and reliability of power system since wind energy is a non-controllable source. Therefore, Transmission System Operator (TSO) and Independent System Operator (ISO) have developed technical requirements for wind power so that power system functions are maintained safely. When the penetration level is low, the dynamic simulation is no needed due to allowing automatic disconnection of wind power during power system disturbances. On the contrary, the automatic disconnection for high penetration level is prohibited due to large impacts to power system. Regarding dynamic stability problems due to large integration of wind power, the testing and simulation requirements to verify dynamic stability are presented.
TSO should maintain and expand simulation models to verify Grid Connection Compatibility (GCC) and analyze power system. Therefore, Grid Code (GC) includes simulation model requirements for wind turbine generator (WTG) and wind power plant (WPP). Most TSOs (German Tennet, Danish Energinet, UK National Grid, Spanish REE, Irish Eirgrid, Canadian Hydro Quebec, Austrian AEMC *etc.*), the international organizations, the local associations and certification bodies have dynamic simulation

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requirements [2-8]. WPP owner that has responsibility for not disturbing dynamic stability should supply the various documents related to dynamic simulation; WTG manufacturer should send dynamic models, model validation report and test report. WPP owner should send dynamic models and commissioning report to TSO.

To related dynamic simulation, a considerable amount of research and study has been conducted. IEA Task Expert Group Report [9] described methodologies, study assumptions and inputs needed to study wind integration. CIGRE WG C4.601 discussed models types suitable for power system studies related to the WPP and appropriate level of modeling detail for analysis [10]. The paper [11] described a dynamic models required to study the dynamic interaction between WPP and power system. For installed offshore WPP of more than 500MW in Belgium, the dynamic simulation decided major grid reinforcements [12]. The concept of model validation and the recent efforts to achieve model validation for WPP are explained in the paper [13]. The process of modeling and simulation, guidelines for model validation, validation process and analysis tool were introduced in [14]. Moreover, Swedish R&D organization ELFORSK investigated dynamic properties and limitations when using a HVDC (High Voltage Direct Current) link, based on transistors to control WTGs [15]. Therefore, everyone related to connecting WPP to power system should understand dynamic simulation requirements clearly so that unnecessary project delay or extra work can be avoided. This paper deals with analysis on dynamic stability verification requirements of developed countries in wind power.

2. Grid Code

2.1. Grid Code Classification

The power system is comprised of main constituents such as synchronous/induction generators, power transformers, transmission/distribution lines, switches, relays, compensators, controllers etc. Since complex interactions between the above constituents, the proper planning and designing to operate power system are essential. Therefore, GCs specifying technical and operational requirements related to the production, transportation and utilization of electric power have developed. As we know, GCs are comprised of some codes as shown in Figure 1 and each purpose is as follows [16].

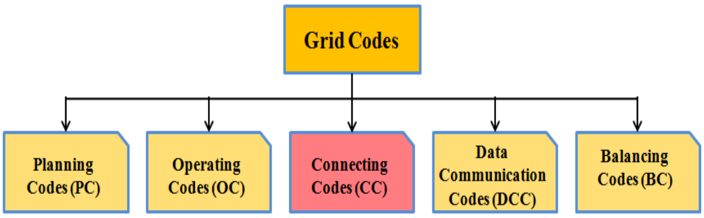

Figure 1. Grid Codes Classification

Planning Codes (PC): are applied when planning or modifying power plants. The technical specifications and procedures planning power system are stated: substation or connection site, transmission lines and other facilities.

Operating Codes (OC): are applied to maintain power supply quality after planning codes and connecting codes are satisfied.

Connecting codes (CC): are considered at the same time as PC for power plants. The technical, design and operational requirements at plant connection point are defined. TSO checks whether these requirements is obeyed or not.

Data Communication Codes (DCC): are obeyed under planning and operating power plants. DCC specifies type, form and security requirements for data being exchanged between power plant and TSO.

Balancing Codes (BC): are considered under operating power plants. The requirements to maintain voltage and frequency range at plant connection point are specified.

2.2. Technical Requirements for Wind Power

Generally, the requirements related to renewable energies are distributed over the above mentioned 5 GCs and mostly contained as a part of the connecting codes. At the latest trends, the requirements are being strengthened since TSO requests renewable energies behaving as the conventional power plants in power system. WPP should observe these requirements, and TSO and certification body should verify GCC. Most TSOs and associations have been made and updated GC for rising impacts of WPP, and typical connection requirements can be summarized as follows.

Tolerance to voltage and frequency deviations: are satisfied by a variety of components while remaining those efficiencies. The continuous or limited WPP operation under operation conditions (normal and emergency) of power system should be possible. This requirement is displayed in minimal operation duration time and reduced active power output according to voltage and frequency deviations.

FRT (Fault Ride Through): should be observed under voltage disturbance (dip or swell) of power system. The larger voltage dip and outage can occur unless WPP is connected in event of disturbance. Therefore, WPP should stay connected to power system in accordance with protective function settings. The requirement is described in minimum connection duration time and active/reactive power outputs according to the varying voltage level. The FRT is classified by HVRT (High Voltage Ride Through), LVRT (Low Voltage Ride Through) and ZVRT (Zero Voltage Ride Through).

Active power control (steady state): is executed in obedience to TSO dispatch orders to avoid imbalances and overloading of power system. This requirement consists of absolute production, delta production and power gradient constraints.

Active power control (dynamic state): is executed to be restored to its pre-fault value during voltage recovery. That is, WPP should help restore the power system to normal operating conditions.

Reactive power control (steady state): is used to ensure efficient operation and voltage control during steady state conditions of power system. The automatic voltage control by continuous changing reactive power output maintains voltage within allowable limits. GC specifies the operation range for reactive power supply of WPP.

Reactive power control (dynamic state): is needed to provide dynamic voltage support under FRT. WPP should inject maximum reactive current to aid recovery to a pre-disturbance state. The amount of reactive current depending on the extent of the voltage drop is specified.

Power quality: should be satisfied and generally the standards such as IEC 61400-21 [17] and EN 50160 [18] are applied. Voltage disturbances such as voltage variations, flickers, transients and harmonic distortions are considered for WPP.

Protection system: is essential to protect healthy parts from faulty components in power system. The protection system in both WTG and WPP should be determined by cooperation with power system. The requirements are explained in relay setting, function time *etc*.

Data communication and signals exchange: are implemented to secure the proper operation between WPP and power system. The requirements for measuring equipment, measuring accuracy and master data should be prepared. All data should be submitted in standard formats such as PDF, XLS, JPEG and DWG.

Verification and documentation: are mainly related to dynamic stability being discussed in this paper. Planning data (size, type and performance) and model data (WTG, WPP, protection and control) should be forwarded to TSO.

3. Grid Code Compatibility

The WPP owner should demonstrate GCC and TSO should assess GCC to ensure no adversely impacts on power system. Therefore, IEC 61400-22 [19] states "grid connection compatibility measurements should be evaluated by the certification body to verify specified reactions (*e.g.* during grid fault conditions) defined in the GC applicable to the site"

3.1. GCC Verification

TSO recommends model validation and compliance measurement (testing) as depicted in Figure 2 [20]. The verification methods, testing and simulation are needed to carry out a verification plan [21]. The GCC testing can represent real behavior of both WTG and WPP, but entails high costs and grid effects. On the contrary, GCC simulation has low costs and no grid effects, but model validation is necessary. Namely, GCC simulation studies are required if demonstrating through testing is impractical due to effects on power system. Therefore, WTG manufacturer makes models and asks an accredited test laboratory to execute type test. WPP owner makes models and asks certification body to verify commissioning testing. The made models are validated with testing reports approved by certification body. Accordingly, for various power system studies, the dynamic models, model validation report and test report should be forwarded to TSO.

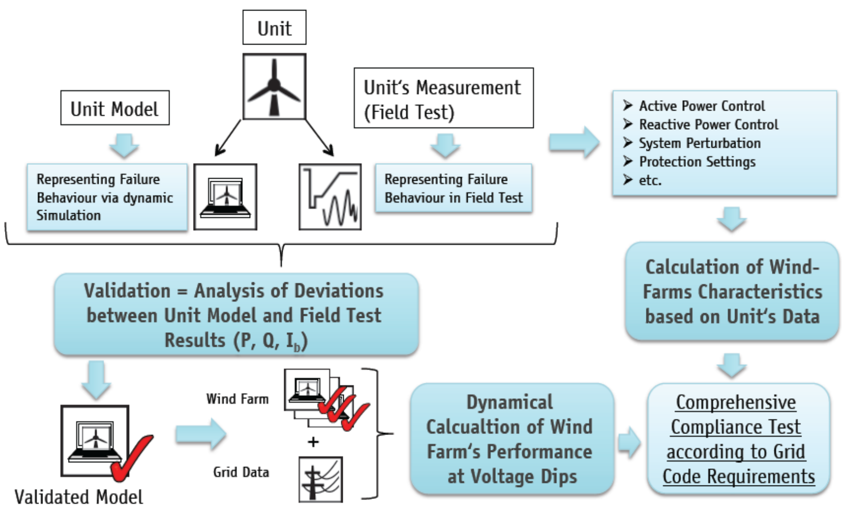

Figure 2. GCC Verification Procedure

3.2. GCC Testing

The GCC testing of both WTG and WPP is performed on-site or off-site so that performances are confirmed and models are validated. The demonstrating through testing should not effect on other users in power system. IEC 61400-21 provides a uniform methodology that will ensure consistency and accuracy in the presentation, testing and assessment of power quality characteristics of grid connected WTG [17]. Moreover, MEASNET "Power quality measurement procedure" [22] and FGW "Technical Guidelines for Power Generating Units-Part 3 Determination of electrical characteristics of power generating units connected to MV, HV and EHV grids" [23] are used for testing. The demonstrating through type testing may be acceptable since testing of every WTG is impractical when different types exist in a WPP. The common types of testing are reactive power capability, voltage control, frequency control, fault ride-through, active power control and reactive power control. As advanced arrangements, WPP developer should provide information no later than 10 days prior to testing: overall single line diagram, technical data, directions to the WPP, site map for WPP and contact details of appropriate personnel on site. Also, wind condition a week prior to and 3 days prior to testing should be checked.

3.3. GCC Simulation

The considerations of analyzing GCC are power system characteristics, WTG technology, grid connection requirements and simulation tools. As regards simulation models, TSO prefers standard models with sufficient accuracy and manufacturer prefers user-written models with intellectual property. Due to confidentiality, simulation models are directly forwarded from WTG manufacturer to TSO. IEC is creating 61400-27 series that specify standard dynamic electrical simulation models for wind power. IEC 61400-27-1 specifies different WTGs (type 1~ type 4) models and model validation procedure [24]. IEC 61400-27-2 will specify WPP models and model validation procedure [25]. GCC testing is performed to tune and verify simulation models, and implementation closed to actual performance is made possible. WTG manufacturer and WPP developer should revise and update models until performance is proved. With adequate models, the power flow calculation, short circuit current calculation, static behavior and dynamic behavior are verified through GCC simulation.

Asociación Empresarial Eólica (AEE) "Procedure for verification validation and certification of the requirements of the PO 12.3 on the response of wind farms and photovoltaic plants in the event of voltage dips" [26] and FGW "Technical Guidelines for Power Generating Units-Part 4 Demands on modeling and validating simulation models of the electrical characteristics of power generating units and systems" [27] are used for simulating.

4. Simulation model Requirements

The specific software, models, and simplifications are necessary for valid and accurate simulation. WTG models are classified as static and dynamic models. Static models used to analyze steady state are simple and easy. Dynamic models are needed for dynamics analysis, control analysis, optimization *etc*. WTG dynamics depend on aerodynamics, mechanical structural dynamics, controller response and electrical system.

4.1. Simulation Models

The requirements for simulation models are associated with model form, minimum functions, encryption acceptation, value form, simulation tool, minimum operation range *etc*.

Block diagram: simulation models should be supplied in the form of block diagrams with major components, which by means of mainly logical and mathematical functions: generator block, power converter/excitation block, pitch control and aerodynamics block, mechanical drive train block and optional protection block.

Source code: should be supplied for model. TSO wants to be able to investigate and find the source of the problem in the event of a simulation failing. Furthermore, source code has more uses in case of moving to new version of software.

Parameter ranges: should be consistent between loadflow and dynamic models and representative of the actual WPP. General frequency range of ±6% (50/60Hz) and voltage range of 0~130% (nominal value) are used.

Simulation tool: once operations limits have been defined, the impacts should be analyzed by suitable simulation tools such as OpenDSS, PowerFactory, PSS®E, ISPA+ and PowerWorld simulator. However, Siemens PSS®E and Digsilent PowerFactory are prevailing recently as professional software platform. The status of software platform used in certification of renewable energy facilities is updated monthly [28].

Time step: is input parameter and simulation model can be complicated according to modeling purpose; if time step is very low (0.1ms), the complexity will be very high. The two main time domain simulations are electromagnetic simulations (EMT) and electromechanical simulations (RMS). Generally, time step is less than ¼ cycle for RMS models and ms level for EMT models. Meanwhile, typical simulation time frame is between 10s~30s.

WPP model includes WTG, FACTS and existing compensation devices, cables, step-up transformers and internal lines. Figure 3 illustrates the different detail levels of model [29]. A detailed model means modeling of every equipment including dozens of WTGs, internal lines etc. An aggregated model means equivalent modeling for all equipment and is recommended for dynamic simulation of WPP regardless of size or configuration. The aggregated model can reduce system complexity and computation time.

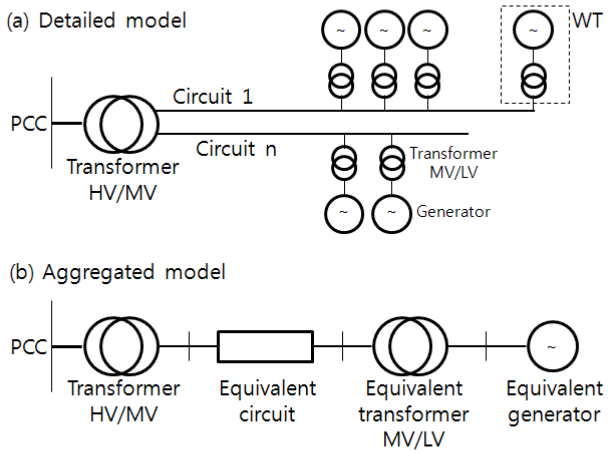

Figure 3. Wind Power Plant Modeling

4.2. Simulation Models Validation

The model validation aims to establish that model and its parameters represent the dynamic performance adequately. Validation is based on the comparison of simulation results with observed actual behavior of WTG connected to power system. The accuracy of simulation models should be specified for the related voltage, active power, active current, reactive power and reactive current. TSO can validate simulation model of WPP through measurements submitted after the final commissioning. The WPP owner having responsibility for performing all validation tests is also responsible for measuring equipment, data loggers and staff.

4.3. Requirements Defined in Each Country

The comparisons of dynamic simulation model requirements are shown in Table 1.

Table 1. Simulation Model Requirements

Code	Block diagram	Specific software	Source code	Encryp-tion	Black-box	Frequency range(Hz)	Voltage range(p.u.)	Time frame	Time step	Aggrega-tion
AEMO	Yes	PSS/E	Yes	no acpt.	no acpt.	disturbance requirement		≥30s	≥1ms	Yes
Energinet	Yes	Power-Factory	Yes	no acpt.	acpt.	47~53	0~1.4	≥30s	Variable time step	No
Eirgrid	Yes	PSS/E	Yes	-	-	disturbance requirement		-	≥5ms	Yes
National Grid	No	Power-Factory	Yes	-	-	disturbance requirement		-	≥10ms	No
WECC	Yes	PSLF™ PSS/E PW	No	no acpt.	no acpt.	minimum disturbance tolerance requirement		20~30s	≥¼ cycle (60Hz)	Yes
REE	Yes	PSS/E	Yes	-	-	-	-	-	≥5ms	Yes
Hydro Québec	IEEE models	PSS/E	No	-	no acpt.	-	-	-	≥4ms(60Hz) ≥5ms(50Hz)	Yes
	Yes				acpt.					

* Siemens PTI PSSE, GE PSLF™, PowerWorld(PW) Simulator, Digsilent PowerFactory
* AEMO (Australia), Energinet (Denmark), Eirgrid (Ireland), National Grid (Great Britain), WECC (USA), REE (Spain), Hydro Québec(Canada)

In Australia, Austrian Energy Market Operator (AEMO) published "Data and model requirements for generating systems of less than 30MW" [30] and "Dynamic model acceptance guideline" [31] in 2013. The data and model requirements are different according to generating system size; ≤5MW, ≤15MW, <30MW and ≥30MW. The unencrypted model source code may not be necessary in case of using generic model and the unencrypted model source code must be provided in case of no using generic model. AEMO accepts the use of generic models for less than 30MW, but a positive sequence RMS-type dynamic model developed in PSS®EV.32 in case of the larger plants. The representation of black-box type is not accepted.

In Denmark [3], the modeling requirements are applied WPP with a rated power greater than 1.5 MW in the same POC (Point Of Connection). The encrypted parts are not acceptable in simulation models. RMS values in the synchronous system (positive sequence) and in the individual phases during asymmetrical incidents and faults must be simulated.

In Ireland, EirGrid published "EirGrid Grid Code" [6] in 2013 and the modeling requirements for wind turbine generators are included in Planning Code Appendix (PC.A.4.10.1). Transmission and distribution-connected WPP greater than 5 MW are required to submit with their application a dynamic model in compliance with PC.A4.10.1.2. Dynamic models should be provided no later than 240 business days prior to their scheduled date of connection to the power system. The dynamic model must represent the features and phenomena likely to be relevant to angular and voltage stability.

In USA, Modeling and Validation Work Group of Western Electricity Coordinating council (WECC) published "Wind power plant dynamic modeling guide" in 2014 [32]. This guide can cover Type 1 (fixed-speed, induction generator), Type 2 (variable slip, induction generators with variable rotor resistance), Type 3 (variable speed, doubly-fed asynchronous generators with rotor-side converter) or Type 4 (variable speed generators with full converter interface) wind turbine generators. WECC requires approved generic models not manufacturer-specific dynamic models, which are public (non-proprietary), accessible to transmission planners and no need for non-disclosure agreements. The models should be initialized based on the power-flow power dispatch. The models should be applicable to power systems with a short circuit ratio of 3 and higher at PCC.

In Spain, the Spanish Wind Energy Association has developed the document "Procedure for Verification Validation and Certification of the Requirements of the OP 12.3 on the Response of Wind Farms in the Event of Voltage Dips" (PVVC) [26].

5. Conclusion

This paper summarizes the dynamic modeling requirements and validation for grid-connected WPP. It becomes more and more important for power system to keep stability from grid impacts according to increasing penetration level of WPP. Since GC is different by country, the simulation model requirements for model form, minimum functions, encryption acceptation, value form, simulation tool and minimum operation range should be understood exactly. The simulation model requirements and procedure are quite complex, and everyone related to connecting WPP to power system should understand these requirements clearly so that the unnecessary project delay or extra work can be avoided.

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