Review and Compliances of Grid Code with Renewable Energy (RE) Integration

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***Abstract*—** The Demand of Electric Power consumption is increasing day by day with the increase in population both in developed and developing countries and power generation by the conventional power plant using fossil fuels is limited up to a certain period. For future prospects, transition to renewable energy sources, which are considered as clean and green energy generated using natural resources like Solar, Wind, Hydro, Ocean, Biomass, Geothermal etc. Generation of electric power with the deployment of RE sources on Grid leads to certain problems related to the stability like voltage flickering, voltage fluctuations, overcurrent, overvoltage, variation in frequency etc. during islanding mode i.e. disconnection from the main grid. Despite these problems, Renewable energy sources could supply surplus power to the local loads but the generation of power requires certain grid code. As Renewable energy output is intermittent, for that renewable asset requires certain Grid code. Earlier, grid code did not include renewable sources assets, thus it needs suitable upgradation. Recent studies have shown the updated Grid code with the inclusion of Renewable Energy sources. This paper addresses a comparative study of updated grid code in developing and developed countries during islanded mode. This study contrasts Germany and Ireland as the developed nations with rapidly expanding economies like India providing insights about the enhancement of integration of Renewable Energy on the grid with the advanced grid code.

Keywords-* Renewable Energy(RE), Wind Power Plant(WPP), Point of common coupling (PCC), Low voltage ride through (LVRT), Federation of German Wind power(FGW), Bundesverband der Energie- und Wasserwirtschaft (BDEW)

I. Introduction

Grid code set the rules for power network control and operation for ensuring stable, secure operation of the power system network. Grid codes point out those electrical executions that affects the system stability. Now a days, RE penetration increasing by including large number of generating units which possess a difficult task on system operator in terms of connection, regulation, planning and operational code. Table 1 shows the increase in wind power penetration in developed and developing nation. For overcoming the above issues, particular agreeability methods and simulation techniques have already been established [1]. Also, utilities and standard authorities all over the World provides numerous grid code for intermittent RE generation while they were connected to their respective grid to protect the system from voltage and frequency fluctuations. Now, grid codes involve Wind Power Plant to endure several grid turbulences, and also maintain system stability like conventional plant [2].
The share of variable renewable energy in power generation is quite higher; Worldwide power generation from wind could be 793 GW and solar energy 613 GW by 2020 [3]. In Germany, the overall solar energy installed was 40 GW till 2015 and it reached 50 GW in 2016 [4]. This shows the generation from variable RE has prominent but there must be a proper strategies otherwise it could affect system frequency and voltage due to sporadic nature. To address these impacts utilities provided certain grid code defined by system operators. Grid code provides technical requirements for the reliable operation when whole system integrated with the variable renewable energy. In the past, the wind or solar power penetration was extremely small with respect to the total generation so requirements for the grid connection were not included in the grid code. During 1980s, wind power generation were actively started and various problem associated with wind generation were faced by the company. During 1990, connection rules were coordinated at national level e.g. wind plants owners and installer of Germany were included in the grid code [5].

In recent years, the rapid development of power generation using variable RE sources leads to reformulation of worldwide grid code at transmission level. For example, Germany was the biggest market in 2015 as far as yearly establishments, introducing 6,013.4 MW of new limit, 2,282.4 MW of which was offshore (38% of aggregate limit introduced in Germany) [3]. Few regulations w.r.t RE was introduced in 2015 originated from the spearheading markets of Germany and Denmark. This is for the most part because of the soundness of the administrative structures in these nations, which gives financial specialists perceivable options on future tasks, money streams and supports interests in wind energy utilization. According to the study [6], developed and developing grid code for WPPs / PV are categorized in 5 explicit conditions: i) LV/HV ride through fault b) Response of total power after disturbances c) variation in voltage and frequency range d) control of frequency and active power e) control of voltage deviation and reactive power.

TABLE 1: INCREASE IN WIND POWER PENETRATION [3]

Countries	Year		
	2014	***2015***	***2016***
Germany (MW)	39	45	45
Ireland (MW)	2.2	2.5	2.9
India (MW)	23	27	32

II. ISSUES IN RE POWER GENERATION MODELLING INCORPORATED IN INTERNATIONAL GRID CODE

Modelling and simulation techniques are required for the analyzing and verification of the system. System administrators have presented particular conditions for the incorporation of energy plant models and recreation systems to be trailed by makers, with a specific condition to check the connection feasibility and the compliance with grid code rules. Simulations of steady state and dynamic models are prior done in order to know the requirement for the real time project with valid proof. It considered power quality, active and reactive power controlling capability and under voltage ride through performance [7,8]. Some issues are analyzed during renewable power generation modelling and summaries are given in Table 2 [1].

TABLE 2: CHALLENGES/ISSUES IN RENEWABLE POWER GENERATION MODELLING

Parameters/ Components/ Equipment	**Potential Issues Faced**
Generators	Modelling needs to be carefully assessed regarding control systems and algorithms which are mostly proprietary.
Unbalanced Condition	Difficulty occurs with positive sequence model.
Connection of RE in weak point	Affect accuracy
Aggregated Simulation	Not adequate at different generator speed
Signal	Impact on controlling system of small signal

To overcome the above issues many reformation regarding simulation test and modelling have been done. For showing the validity of the system, simulation must be complemented by validation assessments. The power quality assessment of WPP can be done by recording current and voltage data at Point of common coupling (PCC), where micro grid is connected with the main grid. The modelling requirement usually includes both the generating unit as well as complete generating system associated with transformer, converter, cable and grid.

First technical grid code regarding interconnected solar power plant was developed by an organization BDEW (Bundesverband der Energie- und Wasserwirtschaft) - Germany in 2008 [9] by considering different technical situations as: i) Low Voltage ride through fault b) Variation in voltage and frequency range c) control of frequency and active power d) control of voltage deviation and reactive power. BDEW organization have set specific prerequisite for solar plant interconnected with the transmission line during symmetrical fault.

i) Low Voltage ride through fault:

To check the capability of the generating unit regarding identifying the voltage dip and riding through the fault is tested by LVRT test. The curve in fig.1 is showing the technical necessities of Germany grid code for Low voltage ride through fault with voltage and time bounds [9]:

Grid code	During fault		After fault	
	V_0 (pu)	t_1 (s)	V_1 (pu)	t_2 (pu)
Germany	0	0.15	0.9	1.5

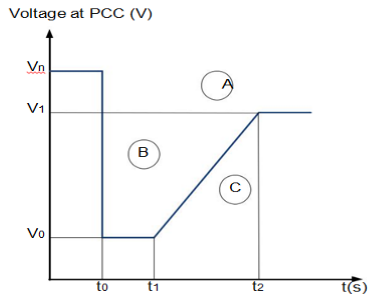

Fig 1. Waveform for FRT

Where, V_n is the normal voltage

Solar power plant works normally at PCC point in Area A and remains connected for a certain time period in Area B but in Area C plant connection is not compulsory. According to the grid code of BDEW, at the time of disturbance, the solar plant withstand voltage drop should be 100%. In fig. 1 time (t_1) is 0.15 sec at which solar plant work normally according to BDEW. After the clearance of fault, voltage will rise till V_1 which is 30% of the normal value at corresponding time (t_2). After t_2 that is recovery time voltage goes in tripping condition.

Reactive power is required for the voltage stability. According to the Germany grid code, 1% voltage drop requires a slope of 2% positive reactive current injection and the dead band zone is 10% without reactive current injection.

b) Variation in voltage and frequency range:

Voltage and frequency boundaries under which solar power plant could operate continuously are established by Germany grid code. The range of voltage is 90 to 110% of the nominal value of the voltage at PCC and the frequency range is quite wide in Germany has shown in Table 3[9].

TABLE 3: DEVIATION IN FREQUENCY

Frequency limit of German code.

Grid code	Frequency	Limits (Hz)	Maximum duration
Germany	50 Hz	f > 51.5	Instantaneous trip
		47.5 of 51.5	Continuous
		f < 47.5	Instantaneous trip

German code permits the instantaneous trip when change in frequency reached the upper range.

The protection and reliable operation of wind plants at the event of the grid fault has been implemented using validated dynamic model for the connection to the German Transmission and distribution systems.

In 1992, Germany set up the first test procedure for power quality measurement at Wind Turbines. Power quality assessment, active and reactive power capability and the protection setting were already included in the grid code [1].

German grid connection regulations (FGW-TG8) [10], presents the guideline for issuing the certification for the system according to the grid code of Germany. The scope is limited to the voltage quality and grid stability.

In 2009, the technical grid code of Germany (FGW TR3, 2011) [11] has been further updated and active, reactive power controlling and voltage dip test procedure were included. The FGW TR3, 2011 finds application for measurement of quality of power for the grid connection of wind turbine.

In German grid code, generating unit is required for modelling whereas in Ireland, modelling requires wind turbine generator model, SVC, converter control relays. 5MW WPP required to validate the above compliances.

Table 4 indicates the documents containing modelling and validation prescriptions required by system operators in developed countries.

TABLE 4: RENEWABLE POWER GENERATING MODELLING AND VALIDATION REQUIREMENTS IN EUROPEAN NATIONS [1]

Country	Title	Technology
Germany	FGW(Federation of German Wind power and other RE), 2011 for determination of characteristics of power generating units and system connected to MV<HV and EHV grids [10].	Wind and other RE
Republic of Ireland	EirGrid [13]	Wind

III. MODELS FOR SIMULATION VALIDATION

Dynamic and static simulations are required for development, operational, interconnection and plant design purposes.

Different time domains i.e. Electromagnetic Transients (EMT) and Root Mean Square (RMS) dynamic models are used in model building for the power system network [1]. A comparative study between these two models has been presented in Table [5].

TABLE 5: COMPARATIVE STUDY OF RMS MODEL AND EMT MODEL

RMS/ Positive Model	EMT/ Positive Model
Integration and stability studies	Effect of fast transients and electromagnetic has been studied
Larger time step so fast in response	Smaller time step resulting time consuming simulation.
Not feasible for unbalanced condition, Adequate for power system network topology	Not feasible for large network
These systems are handled by manufactures in Germany and Australia	Adequate in Balanced condition.

Generic models mainly focus on wind power generation. It is basically compared with the models of the vendor. Comparisons of specified and proprietary models are shown in Table 6.

TABLE 6: COMPARATIVE STUDY OF GENERIC AND PROPRIETARY MODEL

Generic Model/ Specified	**Proprietary Model**
For the accuracy point of view, system operators prefer specified Model.	For high degree of accuracy, equipment manufacturers are concerned with Proprietary Model.
Simple and easily available includes external modules, block diagram or other appropriate information. Also, Software tools are also available like DIgSILENT powerfactory.	It includes user written positive sequence model and description of 3- phase equipment model
Allows exchange of data of the model and easy in comparison under different simulation	

Generic Models have significant advantages like they are used during implementation of positive sequence and transient stability models on large scale, represents wind plants as well as solar PV generation, Reactive power compensation. In Ireland, if library model is not specified then user- written model must be supplied [1].

Generators and Manufacturers must show compliance and validation of technical connection according to the grid code. Compliances mainly carried out by the testing and simulation in all countries for ensuring the precise performance of the system [12], whereas validation consists of simulation, data collection and acceptance of the validity of the model. Compliance verification for RE is a tedious task for that compliance certification process can be used.

Table 7 summaries the process of Compliance verification in Germany and Ireland.

TABLE 7: COMPLIANCE VERIFICATION PROCESSES IN GERMANY AND IRELAND

Germany	**Republic of Ireland**
Verification process include active and VARs power generation based on the given supply, for defined set points having active power control, power quality, frequency deviation, cut-in conditions, performance during faults, and the performance of protective devices. LVRT test determines if the generating unit is capable of detecting voltage drops, with proper description of the testing methodology as per IEC61400-21 standard.[14] For regulation of voltage requirement, tests can be supported out via a suitable grid or a control system which will act as a test bench. Verification processes are complemented by a certification.	Significant technical requirements for wind plants, in terms of active power management, signal communications, controls and transmission system voltage requirement. For the above mentioned, a series of defined tests performance is required at wind farm level with its description for: instrumentation purpose, procedures and passing criteria. Aforementioned tests are carried out on-site without additional equipment facilities, with exception for cases such as frequency compliance test of wind plants. Verification processes are complemented by a certification (pre and post-energization).

IV. Grid Code Issues in India

Ministry of New and Renewable Energy (MNRE) promoted Renewable energy, the central authority for all rules, regulations, policies and approvals relating to renewable energy. Interregional trading of electricity and National grid standards are managed by Central Electricity Regulatory Commission (CERC) and State Electricity Regulatory Commission (SERC) deals with transmission and distribution of power [15].

Intermittent output from solar and wind power generation creates technical problems. The main challenges are voltage excursion and reactive power demand which affects the system. To overcome the voltage associated problem 16 SVCs have to be installed at different point in the Indian grid.

Further modification and studies with the help of international cooperation are required for finding the better result of modelling of renewable energy sources.

Induction type wind generators require reactive power during starting and normal operation period. Wind plant has variable output characteristic; wind generator takes multiple times startup, resulting in enormous absorption of reactive power from the grid causing excursions of voltage [16].

To mitigate the effect of unrequired flow of reactive power to or from the grid, certain measures at RE station shall be provided like Static Var Compensator, Static Synchronous Compensator (STATCOM).

As per Indian Grid Code, the day ahead scheduling on 15 min time block basis for all inter- regional trading are done [13]. Furthermore, bids are hourly or blocks and is done to introduce transparency in the electricity market and reduces counter-party credit risk.32 GW Renewable energy have been planned to be provide in 12th Plan program (2012-2017), costing Rs. 32 crores [17]. For the expansion of RE wind, solar and small hydro "Green Corridors" are made in the states of Jammu & Kashmir, Maharashtra, Andhra, Karnataka , Gujarat, Rajasthan and Tamil Nadu and the main corridors are in the states Gujarat, Tamil Nadu, Rajasthan and AP. The voltage levels of transmission system are of 132 kV, 220 kV, 400 kV, and 765 kV [16].

According to the (IEGC) Indian Electricity Grid Code 2010 states for proper scheduling or power flow from wind energy needs to be forecasting with some accuracy. As per Indian Electricity Grid Code, 70% accuracy could be forecasted on the basis of day ahead [4]. The generation must be within the range of +/- 30 % of the specified to avoid the Unscheduled Interchange charges [17].

A renewable Regulatory Charge comes under Renewable Regulatory Fund is a regulatory charge which come in action January 2011 , in which the total capacity of new wind plants must be 10 MW or above at 33 KV transmission line but at 66 KV line it must have the fault ride through capability[18,19].

In 2013, the power factor for wind power plant should be within the range of 0.95 lagging to leading and the current harmonics injections shall not increase beyond 0.5%of full rated output specified in IEEE Std. 519[20].

V. Overview of Indian Grid Codes

Grid code is a mandatory document for stable and reliable operation of the power system with standards guidelines and rules made by Central electricity regulation commission in section 79 and 178 of the electricity Act 2003 for reliable and secure power [17]. Some updated Indian grid code amendments are given in table 8.

TABLE 8: YEARWISE AMENDMENTS OF GRID CODE [20]

Year	Description
2000	Made by central transmission utility in march 99 and approved in January 2000 by CERC and effective in Feb. 2000
2002	Revision of clause 1.5 is "Reporting of non-compliance" and other various clauses.
	Replacement of "pool account "with "UI settlement system" incorporated with reactive power. Effective from march 2002
2006	w.e.f. Ist April 2006, in which Regional load dispatch shall keep accounts of energy/power flow from the grid.
	Grid codes are specified and the revision followed by CERC standards not by IEGC.
2010	With effect from 3rd May 2010.
	• Concept of control area
	• Integration of RE to the grid
	• Accountability of the States and distribution utilities
	• Free governor operation was restricted
2011	Scheduling of Renewable energy was Implemented
2012	Wind generation 10 MW or above at 33 kV.
	Forecast of solar energy provides on the basis of weather condition and solar insolation.

Inter-regional grid code shall supervise, develop and maintained by National load dispatch center (NLDC) with RLDC in which all generating station comply with the standards [21].

VI. Conclusion

The updated grid code of Germany, Ireland and India has been presented in this paper. In addition, for assurance of the model behavior with the real system various models, validation requirement and verification of the plants have been reviewed. Also, LVRT capability under symmetrical fault condition with German grid code has been considered. Germany is the leading country in RE power generation and the share of RE generation in the coming time will increase rapidly so German and other European country Grid code planned to provide ancillary services to the RE plant like fault ride through as well as power control strategy, deviation in frequency and voltage control to make RE plant performance more effective although, Renewable energy source certification has been provided by Germany. For providing the reactive power provision STATCOM and Static Var compensator are provided at the point of common coupling while frequency control in RE is stimulating. However, all nations' grid code is trying to find out the solution regarding frequency control. Distributed micro grids and roof top based solar power plants have great scope for supplying the power with RE power plants. In India the penetration level is of 70% and the price has already dropped down by 50% in the last 5 years due to tariff but there is no change in price of energy generated by wind power plant. There is further need of technology and policies to increase the power flow from Renewable energy Sources.

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