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Improvements in the Development of Grid Code and Review of Power Quality Requirements for Fluctuating Wind Power Generation in India

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This paper deals with the improvements in the Indian grid code and the important point in the power quality requirements. It reviews the Indian grid code and the grid code requirements for wind energy conversion systems and the modifications in the Indian wind energy grid code is presented for further improvements. Power quality issues and requirements in the grid integrations are briefly explained. The main objective of the power quality review is to study the basics of power quality, standards, measurements and the devices used to improve the power quality. The current The International Electrical Commission (IEC) standards were described and the measurements standards are presented. The power quality problems associated with grid integration like voltage fluctuations or flicker; harmonics and interharmonics; voltage drops; active power; reactive power; grid protection and reconnection time are studied and the implementation of the measurement and assessment procedures, specified by the various standards are discussed.

Keywords: *Grid code, Power quality standards, Reliability, Flicker, Harmonics and Measurements.*

1.0 INTRODUCTION

Wind is a freely available resource for power generation. Extraction of power from wind is cheaper than solar energy system. In the renewable energy the running cost is negligible compared to conventional power plant and the value of fuel saving is very high. Wind energy is the rapidly developing technology in the world. Due to the increase in the diameter of the wind turbine, the wind power penetration to the grid is also increasing. When the penetration of wind power increases, the power quality problem also increases because of the power electronics components present in the process. A major power quality problem causes severe losses to the producer as well as the life span of the system. Wind farms are generally located in remote areas far away from load Centre; being so long, transmission lines are required to transmit the power to the customers, this is the one of the main reason for the power quality problems in the wind farms.

Depending on the speed of wind, the power generation capacity increases in a particular place. In India Tamil Nadu, Gujarat, Rajasthan, Karnataka and some other places are identified as suitable for wind power generation, and in Tamil Nadu, Muppandal area is identified as a highly windy area. Muppandal region in Tamil Nadu has the distinction of having one of the largest concentrations of wind turbines at a single location with installed capacity of more than 1000 MW. Wind farms are spread along the national highway from Muppandal to Kanya Kumari, at the confluence of the Bay of Bengal, Arabian Sea, and the Indian Ocean. The Aralvaimozhi mountain pass intensifies the winds of South-West monsoon, which blow from May to September and reaches an average speed of 12–13 m/s. The annual average wind speed in this area is 5–6 m/s [1].

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The power quality is defined as set of parameters defining the properties of the power supply as delivered to user in normal operating condition in terms of continuity of supply and characteristics of voltage and frequency. Team of Riso National Laboratory and Danish Utility Research Institute, Denmark and Electronic Research and Development Centre, India in November 1998 has identified the critical power quality issues related to integration of wind farms. The individual units can be of large capacity up to 5 MW, feeding into distribution network, particularly with customers connected in close proximity. However, with rapidly varying voltage fluctuations due to the nature of wind, it is difficult to improve the power quality with simple compensator. Advance reactive power compensators with fast control and power electronic have emerged to supersede the conventional reactive compensator. The wind power in the electric grid system affects the voltage quality. The electrical characteristics of wind turbine are manufacturer's specification and not site specification [2].

This paper, first discusses the review of Indian electricity grid code, in section 2, review of grid connection code in wind farms, section 3 and section 4 suggests the Improvements in the connection code of Indian wind farms, section 5 explains the basics of power quality, Section 6 gives the various standards, section 7 points out the power quality Requirements for Grid integration, Section 8 gives power quality measurement and the conclusion is drawn in the section 9.

2.0 REVIEW OF INDIAN ELECTRICITY GRID CODE

A shot review of the grid code reported by the central electricity authority is presented here [3]. The Indian Power System containing the following aspects namely

(a) generating stations
(b) transmission or main transmission lines
(c) sub-stations
(d) tie-lines
(e) load dispatch activities
(f) mains or distribution mains
(g) electric supply-lines
(h) overhead lines
(i) service lines
(j) works

The main Objective of Indian Electricity Grid Code (IEGC) is to bring together in a single set of technical and commercial rules for grid integration. In addition, Facilitation of the development of renewable energy sources by specifying the technical and commercial aspects for integration of these resources into the grid.

Structure of the IEGC

1. Role of various Organizations and their linkages
2. Planning Code for Inter-State transmission
3. Connection Code
4. Operating Code
5. Scheduling and Dispatch Code
6. Miscellaneous

Special requirements for Solar/ wind generators are

(i) State Load Dispatch Centres (SLDC)/ Regional Load Dispatch Centre (RLDC) may direct a wind farm to curtail its VAr draw/injection in case the security of grid or safety of any equipment or personnel is endangered.

(ii) During the wind generator start-up, the wind generator shall ensure that the reactive power draw (inrush currents in case of induction generators) shall not affect the grid performance.

To meet the above objectives, Data Acquisition System facility shall be provided for transfer of information to concerned SLDC and RLDC. National Load Dispatch Centre (NLDC)/RLDC are authorized to defer the planned outage in case of any of the following, taking into account the statutory requirements

- i. grid disturbances
- ii. System isolation
- iii. Partial Black out in a state
- iv. Any other event in the system that may have an adverse impact on the system security by the proposed outage.

2.1 Summary of Tamil Nadu Electricity Grid Code

Structure of the Tamil Nadu Electricity Grid Code is given below:

- a) Functional responsibilities of entities connected with the State Grid
- b) System Planning
- c) Grid Connectivity conditions
- d) Requirement in Grid Operation
- e) Scheduling and Dispatch
- f) Commercial issues and Implementation
- g) Non Compliance

The State Transmission Utility (STU) who has to play a key role in the implementation of the Grid Code may be required to act decisively for maintaining the Grid regimes for discharging its obligations.

The objective of the Tamil Nadu Electricity Code is to define the services rendered by each wing in the overall electric system and also for identifying the responsibility and performance factor and measurement points for each one of them. Further, it facilitates intra state transmission and wheeling of electricity, with a focus on the operation, maintenance, development and planning of the Tamil Nadu State Electricity Grid.

3.0 REVIEW OF GRID CONNECTION CODE IN WIND FARMS

Figure 1 shows the general grid connected Doubly Fed Induction Generator (DFIG) wind farms. DFIG generator is widely used in wind farms. As a variable speed generator, it has the ability to capture more power from the wind. In addition, it is a flicker free generator. It is possible to control rotor and the grid separately.

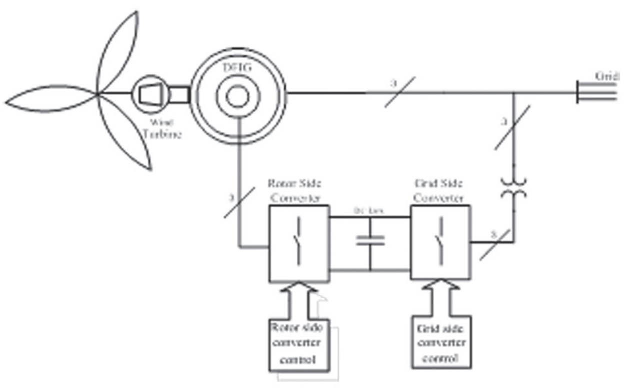

FIG. 1 GENERAL SHUNT TYPE GRID CONNECTED DFIG WIND FAM.

The main technical Issues in wind farm connection to the grid is

- (a) Voltage and reactive power control.
- (b) Frequency control.
- (c) Fault ride-through capabilities.

These are the three main points that new grid codes must adapt for wind farm connection. The most worrying problem that wind farms must face is a voltage dip in the grid. The effects of transient faults may propagate over very large geographical areas and the disconnection of wind farms under fault conditions could pose a serious threat to network security and security of supply because a great amount of wind power could be disconnected simultaneously [4].

Bharat Singh et al. [5] says that "active power control" is also important for transient and voltage stability enhancement. Also, draft report on Indian wind grid code [6] given the following aspects in the connection code

- Transmission system voltage requirements
- Reactive power capability of wind farms
- Frequency tolerance range
- Active power control
- Situation where wind turbines can be disconnected from grid
- Situation where wind turbines must remain connected to the grid
- Ability to withstand repetitive faults
- Protection
- Signals and data communication requirements
- System regarding instruments
- Wind farm equipment
- Auxiliary supply
- Revenue metering
- Procedure for site access, operational activities and maintenance
- Responsibilities for operational safety

Table 1 shows the voltage withstands limits of Indian wind farms.

TABLE 1

VOLTAGE WITHSTANDS LIMITS OF WIND FARMS [6]

Voltage (kV)			
Nominal	**Limits of variation (%)**	**Maximum**	**Minimum**
400	+5 to -10	420	360
220	+11 to -9	245	200
132	+10 to -9	145	120
110	+10 to -12.5	121	96.25
66	+10 to -9	72.5	60
33	+5 to -10	34.65	29.7

The full capabilities of wind farms may not be exploited at all times. Therefore, the connection codes should be such that it should provide the maximum power output from the wind farm without affecting the existing grid operation. The following aspects are taken into consideration for large-scale grid integration of wind power in India [7]:

- Active power control,
- Reactive power control,
- Fault ride through capability,
- Communication requirements,
- Others (modeling and validation, power quality, start and stop, metering etc.)

T.R. Ayodele et al. [8] pointed out that the system must maintain a balance between the aggregate demand for electric power and the total power generated by all power plants feeding the system.

Power balance requires that: Power generated at the source = Power transmitted to the sink + Losses, power balance concept must be implemented in the controller to keep the system stable. At the utility side, the current waveform can be commanded to have an adjustable power factor at minimum current distortion while maintaining the DC bus voltage constant (power balance) [9].

4.0 IMPROVEMENTS IN THE CONNECTION CODE OF INDIAN WIND FARMS

Problem Statement:

As wind speeds are frequently changing and fluctuating, it is necessary to install additional reserves to manage the system power balance and stability, otherwise large unexpected fluctuations, and power oscillations occur in wind power. It can cause additional loop power flows through the transmission grid, these large power deviation has to be balanced by other sources, and these sources are not necessarily located near the wind park. As per Indian grid code requirements, the reactive power compensation equipment must remain connected during system fault, thereby avoiding the need for exchange of reactive power particularly under low-voltage condition. Also in Indian grid connections, the fault occurrence and fluctuations are very frequent. Therefore, it is necessary to manage as per International Council on Large Electric Systems (CIGRE) [10]. Suggested improvements in Indian wind power grid connection code is

1. Congestion management procedure
2. Power flow and power balance control (Active, Reactive and frequency)
3. Fault Ride Through capability (including ZVRT, LVRT, HVRT)
4. Communication requirements
5. Others (Stability, Power quality and Metering etc)

5.0 BASICS OF POWER QUALITY

The Information Technology Industry Council (formerly known as the Computer and Business Equipment Manufacturers Association) first developed the ITI (CBEMA) Curve (Figure 2), which is the basic of the modern power quality standards. The basic function causing the power quality problems are given below [11]

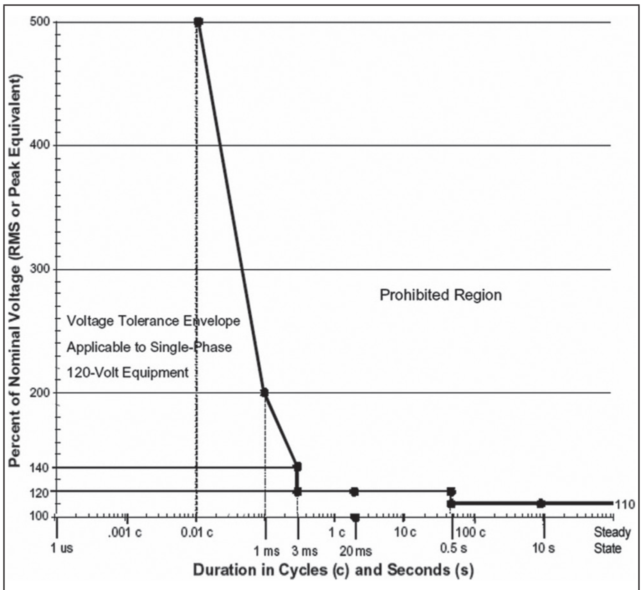

FIG. 2 ITI (CBEMA) CURVE (REVISED 2000).

5.1 Reclosing

Due to distribution faults or short circuits, the power is disconnected for short time or long time then it is reconnected. This is also called reclosing operation. Because of the circuit reconnection the power quality problems will occur.

5.2 Voltage Sags

The flow of fault current reduces the voltage at the substation bus for that phase. The other two phases experience some increase in voltage (swell). Thus, for a fault on one circuit, the customers on that phase on all three circuits experience voltage sag until the circuit breaker has opened.

5.3 Capacitor Switching

Capacitor switching is an everyday occurrence on a utility system to achieve better voltage control and reduce loses. Capacitor bank energizing typically results in an oscillatory voltage transient having a natural frequency somewhere between 300 Hz and 900 Hz.

6.0 STANDARDS

The IEEE is the main standard making body in the United States also American National Standards Institute (ANSI), and equipment manufacturer organizations, such as the National Electrical Manufacturers Association (NEMA) is some of the other organization in America.

The International Electrical Commission (IEC) is a worldwide organization that prepares and publishes international standards for all electrical, electronic, and related technologies. The IEC has defined a category of standards called Electromagnetic Compatibility (EMC) Standards that deal with power quality issues [11] and the details of standards are given below. This commission started work to facilitate for power quality in 1996. As a result, IEC 61400-21 was developed and today most wind turbines manufacturers provide power quality characteristic data accordingly, it specifies a method that uses current and voltages time series, measured at the wind turbine terminals, the details of standards mention by Juan Manuel Carrasco et al. is given below [12].

6.1 Reliability Standards

IEEE Standard 1366, given the guide for Power Distribution Reliability Indices.

6.2 Power Quality Standards

ANSI C84.1 establishes acceptable ranges of steady-state voltages for equipment as well as distribution systems. IEEE Standard 1100 presents the engineering principles and practices for supplying power and grounding of sensitive electronic equipment. IEEE Standard 1250 describes the electrical environment along with various solutions to power quality problems. IEEE Standard 1159 followed with a more rigorous and in depth set of definitions for monitoring of power quality.

The standard EN 50160 is the most important one for de fining the quality of the supply voltage. There is also the IEC 61000 series of technical norms on electromagnetic compatibility (EMC) [13].

1. IEC 61000-3-6 (1996-10): "Electromagnetic compatibility (EMC) – Part 3: Limits – Section 6: Assessment of emission limits for distorting loads in MV and HV power systems".
2. IEC 61000-3-7: "Electromagnetic compatibility (EMC) – Part 3: Limits – Section 7: Assessment of emission limits for fluctuating loads in MV and HV Power Systems".

6.3 Harmonic standard

IEEE Standard 519 is the principal harmonic standard used in the United States and it recommends the limits of the harmonics. High amount of harmonic current leads to capacitor bank failures. The intent of IEEE 519 is to limit harmonic current injection into power systems and ensure voltage integrity. However, when IEEE 519 is applied to single-phase system connections, it can become highly impractical. Presently, IEEE Standard 519–1992 addresses harmonic limits at the consumer and service provider interface. IEC61000-3-2 is also used for harmonic current.

6.4 Flicker standard

The commonly used flicker standard is IEC 61000-3-3 and IEC 61000-3-11.

7.0 POWER QUALITY REQUIREMENTS FOR GRID INTEGRATION

Grid connected wind turbines are considered as potential sources of bad power quality and high amount of voltage penetration in the grid serious power quality problems. Variable-speed wind turbines have some advantages concerning flicker but the force-commuted inverters present in the generator causes harmonics and interharmonics problems [12].

IEC standard consists of three analyses.

1. Flicker
2. Switching operations
3. Harmonic analysis

7.1 Voltage quality and Flicker

Voltage quality is the main power quality problem it has two types

1. Voltage variation
2. Flicker

7.1.1 Voltage variation

– Voltage dips and interruptions, that are reductions of the voltage magnitude at a point in the electrical system below a specified threshold;

– Voltage swells, that are an increase of the voltage at a point in the electrical system above a specified threshold;

– Voltage unbalance, that is a condition in a polyphase system in which the root mean square (rms) values of the line voltages (fundamental component), or the phase angles between consecutive line voltages, are not all equals.

Table 2 shows the voltage unbalance limits of Indian wind energy grid code.

TABLE 2

VOLTAGE UNBALANCE LIMITS [6]

Voltage level (kV)	Unbalance (%)
400	1.5
200	2
< 200	3

7.1.2 Flicker

Flicker means voltage magnitude fluctuation or variation. The flicker may be mitigated by regulating the reactive power with the variation of the real power. Light flicker, which is produced by rapid amplitude fluctuations in voltage that typically cause visible changes in light from electric lighting sources. It has two types:

1. Flickers during operation.
2. Flickers of the supply voltage or during switching, that is produced by changes in power system configurations and/or loads which normally happen during time and result in changes of voltage magnitude.

Specific values are given for fast variations in Voltage, short-term flicker severity, long-term flicker severity and the total harmonic distortion [14]. The presence of harmonic and reactive power in the grid is harmful, because it will cause additional power losses and malfunction of grid component. FACTS devices are commonly used to enhance the power quality, the details are available in [15].

8.0 POWER QUALITY MEASUREMENT

The fundamental reference for power quality monitoring instruments is the standard EN 61000-4-30. The measurement and assessment of the power quality characteristics of the grid-connected wind turbines is defined by IEC Standard 61400-21 (wind turbine system) prepared by IEC Technical Committee 88. IEC 61000-4-15 is the standard, which is very useful for the measurement of flicker [16].

9.0 CONCLUSION

This paper presented the review of Indian Electricity Grid Code and the Indian grid code for wind energy. After reviewing the grid the improvements required in the grid code, is presented. It has concluded that congestion management procedure and power-balancing control is very important in the Indian wind energy grid code. This paper also summarizes the power quality problems, standards, and measurements for the wind energy applications.

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REFERENCES

[1] Carolin Mabel M and Fernandez E. “Analysis of wind power generation and prediction using ANN: A case study”, *Renewable Energy*, Vol. 33, pp. 986 – 992, 2008.

[2] Sharad W Mohod and Mohan V Aware. “Power quality and grid code issues in wind energy conversion system”, http://dx.doi.org/10.5772/54704.

[3] http://powermin.nic.in/transmission/pdf/Indian_Electricity_Grid_Code.pdf

[4] de Alegria I M et. al. “Connection requirements for wind farms: A survey on technical requirements and regulation”, *Renewable and Sustainable Energy Reviews*, Vol. 11, pp. 1858 – 1872, 2007.

[5] Bharat Singh, Singh S N. “Wind power interconnection into the power system: A review of grid code requirements”, *The Electricity Journal*, Vol. 22, No. 5, pp. 54–63, June 2009.

[6] PRDC. “Draft report on Indian wind grid code”, *Center for Wind Energy Technology*, India, July 2009.

[7] http://www.cwet.tn.nic.in/Docu/Wind_grid_code_for_India%20.pdf

[8] Bharat Singh, Singh S N. "Development of grid connection requirements for wind power generators in India", *Renewable and Sustainable Energy Reviews*, Vol. 15, pp. 1669–1674, 2011.

[9] Ayodele T R, et al. "Challenges of grid integration of wind power on power system grid integrity: A review", *International Journal of Renewable Energy Research*, Vol. 2, No. 4, 2012.

[10] Carlin P W, Laxson A S and Muljadi E B. "The history and state of the art of variable-speed wind turbine technology", *Technical report, National Renewable Energy Laboratory*, NREL/TP-500-28607, February 2001.

[11] CIGRE, *Technical Brochure on Grid Integration of Wind Generation*, July 2009.

[12] http://nunobarros.weebly.com/uploads/4/0/6/5/4065994/grid_integration_of_wind_generation.pdf.

[13] Daniel J Ward. "Power quality and the security of electricity supply", *Proceedings of the IEEE*, Vol. 89, No. 12, December 2001.

[14] Juan M Carrasco, Franquelo L G, Jan T Bialasiewicz, Galván E, Ramón C P Guisado and Prats A M. "Power-electronic systems for the grid integration of renewable energy sources: A survey", *IEEE Transactions on Industrial Electronics*, Vol. 53, No. 4, pp. 1002–1016, August 2006.

[15] Cobben S. "Power quality implications at the point of connection", *Ph.D. Thesis*, 2007.

[16] Machmoum M, Hatoum A and Bouaouiche T. "Flicker mitigation in a doubly fed induction generator wind turbine system", *Mathematics and Computers in Simulation*, Vol. 81, pp. 433–445, 2010.

[17] Hansen L H et al. "Conceptual survey of generators and power electronics for wind turbines", *Risø National Laboratory*, Roskilde, Denmark, December 2001.

[18] Daniele G, Landi C and Luiso M. "Issues in the characterization of power quality instruments", *Measurement*, Vol. 43, pp. 1069–1076, 2010.