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Measurement and Analysis of Power Quality Issues in Wind Farms-A Real case study

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Abstract:
Electrical Power Generation by non conventional means, especially wind and solar power, is gaining popularity there by inviting more attention to supply good quality power to the grid. Considerable amount of wind power is being generated and fed to the grid in Coimbatore District in Tamilnadu (India). However, lots of power quality issues are faced by them leading to frequent tripping of generator apart from power evacuation problem due to weak grid. This paper focuses only on identifying the power quality issues in different wind farms substations The issues like sag, swell, transient, interruption flickering and Harmonics occurring the wind farm are monitored according to standard IEC6100-21 by Fluke 435 and Dranetz power quality analyzers at the wind farms substation. The field measurements results give deep insight in to the actual effects of the integration of large wind power sources within the power system. The fixed speed wind farm contributes more number of issues and exceeding the standard limit of power quality than the variable speed wind farm. A detailed analysis is carried out in the proposed work aiming at identifying the major cause for the reduction in the quality of power.

Keywords- Power quality analyzer, Transients, Swell, Sag, Interruption

I. Introduction

Nowadays, the generation and utilization of wind energy resources are receiving lot of attention by scientists and engineers from almost all the countries due to shortage of fossil energy and devastation of the natural environment. Thus, the generation of electrical energy from wind should be with less cost without compromising the quality of power to fulfill the customers' satisfaction [1]. With increases in the integration of wind power into the gird, the power quality problem is becoming more and more serious. However, the power quality at the wind farm has a direct impact on power system and hence it is necessary to continuously monitor the same [2-5].Power quality monitoring helps in taking the right decision for maintaining the quality of power by the manufactures, wind farm operators and network operators. This helps in improving the system stability, power quality and the turbine reliability [6-9]. For the power quality measurements, it is required that wind turbines connected to the power grid should be compatible with the International Electrotechnical Commission (IEC) Std. 61400-21 [10]. This standard specifies the requirements for the measurement and assessment of harmonics, voltage sag, voltage swell, flickers, and voltage drops of grid-connected wind turbines. A case study is carried out different places in India to measure the power quality issues of fixed speed wind farms. Based on the measurement and analysis, preliminary recommendations for grid integration of wind turbines in weak grids are formulated [11]. The generations of power quality issues in the power system depends on grid MVA, wind speed fluctuation, X/R ratio and load variation. Therefore, the preliminary studies have to be conducted at each wind farm substation before it is integrated into the grid.

The aim of the proposed work is to measure and analyze the power quality issues that occur in the wind farms at individual wind turbine and group control breaker of the substation. Voltage sag, swell, transient, flicker and interruption are measured according to standard 6100-21 using Fluke435 and Dranetz PX5.8 power quality analyzers. The power quality data from different wind farms helps us to identify the reliability and quality of generated power into the power system.

The structure of the paper is the following. In Section II, the wind power plant where the measurements are carried is described. In Section III, the implementation of the methodology of measurement is presented. Section IV deals with the in depth analysis of the measured data and conclusions are listed in Section V.

II. Wind farms under study

The fixed and variable speed wind farms located at Coimbatore district, Tamilnadu (India) are identified for measuring the power quality issues. The types of generators in substation of the wind farms are discussed as below:

a. Fixed Speed Wind Farm with Squirrel Cage Induction Generator

Squirrel-cage induction generator (SCIG) wind turbine is the most sought after machine due to its mechanical simplicity and robust construction [12]. The rotor is provided with metallic bars, which are resistant to the effects of dirt and vibration. The power quality analyzer Fluke 435 is connected at individual wind turbine and another one Dranetz PX5.8 is connected at the group control breaker in the substation. Six units of fixed speed wind generator, erected by Suzulon Pvt Ltd, which are stall controlled, each rated at 600kW, 690V are connected to 800kVA, 0.69/11kV generator transformer. The total capacity of the wind farm is 3.6MW which is connected to substation feeder 3. The wind farm substation consists of 11 feeders of different capacity and connected to 11kV busbar. Two identical 16MVA, 11/110kV transformers are connected to the substation busbar 110kV from 11kV bus.

b. Variable Speed Wind Farm with Doubly fed Induction Generator

The doubly fed induction generator (DFIG) is widely used for variable-speed generation and one of the most preferred generators for wind-energy applications [13]–[15]. In these wind generators, slip power is synchronized with stator power by the full-scale power converters (FSC).The wind farm substation is erected by Gamesa Pvt Ltd. The 12 units of variable speed wind turbines are connected to doubly fed induction generator, each rated at 600 kW, 11kV with 800kVA, 11/33kV generator transformer. The total capacity is 7.2 MW which is connected to feeder 2. The substation, consisting of four wind farm feeders of different capacity, is connected to 33kV busbar. The two 25MVA, 33/110kV transformers are connected between 33kV busbar and 110kV substation busbar. The power quality analyzers are connected at feeder 2 to record the power quality indices.

C. Variable Speed Wind Farm with Synchronous Generator

The wind turbine with synchronous generator is considered as one of the most-promising technologies [15-18] for multi-MW wind-energy systems. Excitation is provided either with rotor windings or with permanent magnets. To regulate the generator power and frequency, a full scale converter is connected between the generator and gird. The substation is constructed and commissioned by Enercon Pvt Ltd in the year 2008. The substation has fourteen wind farm feeders (E1-E14) of different rating that are connected to a 22kV busbar. Each turbine of the wind farm is capable of generating 0.85MW at 0.44kV and is connected to a transformer of rating 0.950MVA, 0.44kV/22kV. The HT side of the unit transformer of the wind generator is connected to the 22kV bus bar. With two identical transformers of capacity 50MVA, 22/110kV are connected between 22kV and 110kV busbars. The fluke 435 meter is installed at individual wind turbine presented at E2 feeder and Dranetz is installed at the group control breaker of the 110kV busbar.

III. Technical Details of Power Quality Analyzers

In order to evaluate the Power Quality of the system with conformity to IEC 6100-21/EN50160 Standard, two data loggers, Fluke435 and Drantez PX5.8, are installed. Some of the important features of the data loggers used are listed in belw.

a.Power Quality Analyzer Fluke 435:

Fluke-435 offers the best in power quality analysis introducing the ability to monetarily quantify energy losses. The power wave function captures fast RMS values with an accuracy of ±0.2% of the nominal voltage, allowing inspection of the interaction of voltage, current and frequency. The selectable nominal voltage range is between 1 to 1000V according IEC61000-4-30. It has a resolution of 16 bit analog to digital converter with 8 channels and sampling speed of 200kS/s. It can measure true-rms, peak voltage and current, frequency, swells, transients, interruptions, power demand, harmonics up to the 50th, inter-harmonics, flicker, mains signaling, inrush and unbalance. Every time an event or voltage distortion is detected, the instrument triggers and automatically stores voltage and current waveforms on all three phases and neutral. Hundreds of dips, swells, interruptions and transients are captured this way. Voltage transients up to 6kV occurring for even 5 microseconds can be recorded.

b. Power Quality Analyzer Dranetz PX5.8:

The resolution of Dranetz PX5.8 is 12 bits having a sampling rate of 12.8 kS/s for the analog to digital converter. It has RMS accuracy of ±0.1% of reading+0.05% full scale. Over 7kHz bandwidth provided in the instrument measures flicker according to IEC 61000-15, complying with IEEE 1159, IEC 61000-4-30 Class A. The instrument probes can measure voltages up to 600V. The three current probes LEM FLEX RR3035 allow current ranges of 30/300/3000A respectively having bandwidth between 10Hz to 50Hz with accuracy of 1%. Applications range from acquisition, display to recording of mains quantity through energy consumption up to recognition, statistical calculation, analysis and presentation of voltage characteristics of electricity in accordance to IEC 6100-21/EN56010.

IV. Measurement Results and Discussion

The power quality issues are measured at fixed speed induction generator (IG), variable speed doubly fed induction generator(DFIG) and variable speed synchronous generator (SG) wind farms are located at Coimbatore district, Tamilnadu (India). The power quality disturbances are recorded for nearly forty days between the months of July and August as the wind flow was at the maximum. The measurements are carried out at the wind farms site as follows.

Fixed speed wind farm - 11.7.2011 to 21.8.2011(40 days)

Doubly fed induction generator wind farm -13/07/2012 to 24/08/2012 (43 days)

Variable speed converter fed synchronous generator wind farm - 16/07/13 to 24/08/13 (40 days)

The various power quality events are recorded at the wind farm substation such as transient, voltage sag, voltage swell, interruption, flickering and harmonics.

a.Transient

The term transient is defined as a surge that occurs in a voltage wave from for a short duration of time. These terms reflect the wave shape of a current or voltage transient. The transients can be classified into two categories impulsive and oscillatory.

Impulsive transient
An impulsive transient is a sudden, non power frequency change in the steady-state condition of voltage, current, or both, that is unidirectional in polarity (primarily either positive or negative). Due to the high frequencies involved, impulsive transients are damped quickly by resistive circuit components and are not conducted far from their source.

Oscillatory transient
An oscillatory transient consists of a voltage or current whose instantaneous value changes with polarity rapidly. Oscillatory transients with a primary frequency component are greater than 500 kHz and a typical duration of the order of micro seconds (or several cycles of the principal frequency) are considered as high-frequency oscillatory transients. Back-to-back capacitor energization results in oscillatory transient currents in the tens of kilohertz. The fig 1 below shows the actual recorded transient at the wind farm.

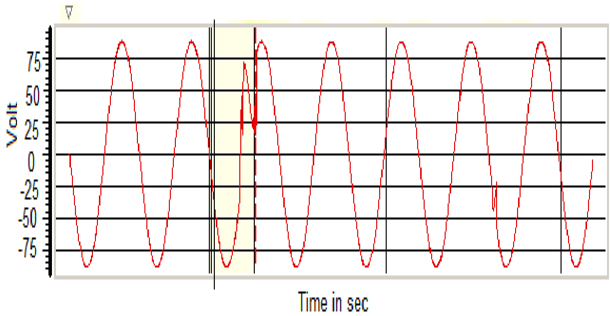

Fig 1: Recorded Transient event

b.Voltage sag and swell events
Voltage sag is a decrease of voltage between 0.1 to 0.9 p.u rms for the duration of 0.5cycles to less than 1 minute. The reason for the occurrence of sag is mainly due to sudden changes in the load and fault level. Voltage swell is an increases of voltage between 0.1 to 0.9 p.u for the duration of 0.5 cycle to less than 1 minute. The swell event occurs due to sudden removal of load from the grid. The fig 2 and Fig 3 shown below are the recorded sag and swell events at the windfarm

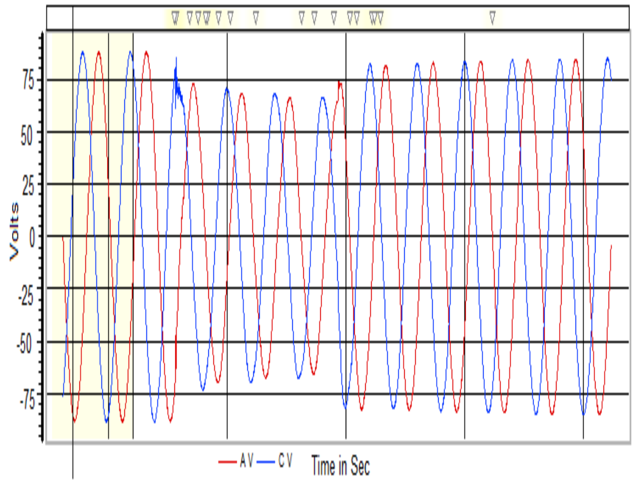

Fig 2. Recorded Sag event

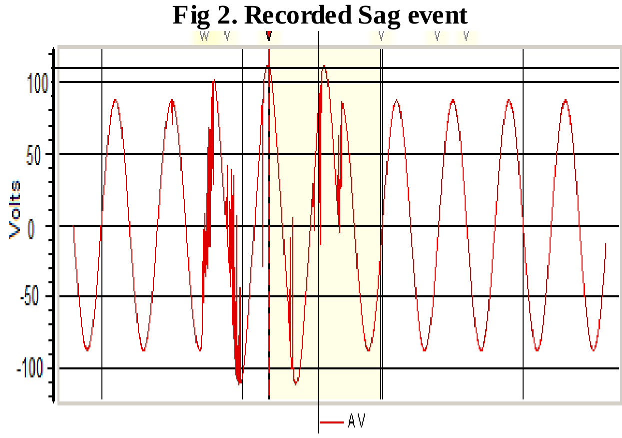

Fig 3. Recorded Swell event

c. **Interruption**
A variation in the voltage waveform for a short duration and complete loss of voltage (< 0.1 pu) on one or more phase conductors for a time period between 0.5 cycles and 3 s.
The number of events recorded during the field trips at the wind farms are shown in Table 1. The compliance power quality reports are taken from the Dranetz power quality analyzer during the measured period is as shown in Table 2. It is indicating the duration of events from 10msec to 3min and percentage of voltage drop from the nominal. The fig 4 below is the recorded interruption in the wind farm

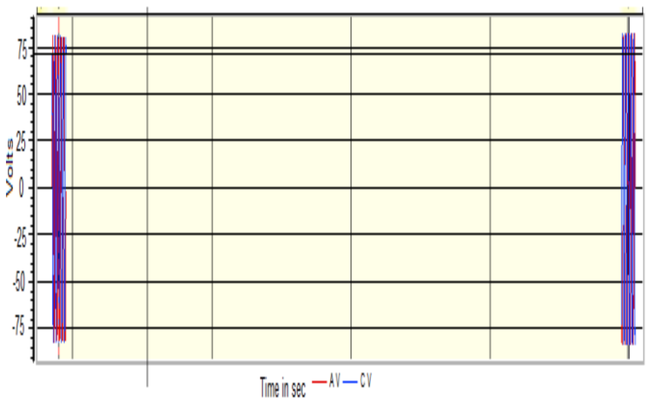

Fig 4. Recorded Interruption event

d.Flickering

Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time is termed as flickering. According to the IEC 61400-21 standards, the flicker severity value P_{st} is lesser than one. The flicker emission depends on grid impedance angle, short circuit ratio, tower shadow effect and wind fluctuation[19-20]. Both the variable speed wind farms emit the P_{st} values within the standard limit, but the fixed speed wind farm generates the high flicker emission which are exceeding the limit as shown in the Fig 5.

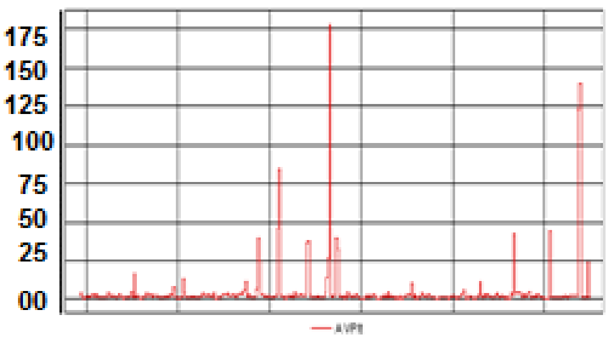

Fig 5. Recorded flickering event

e. **Harmonics**

Harmonic distortion is another power quality problem associated with wind power generation. Voltage deviations from the perfect sinusoidal wave shaped 50Hz curve give harmonics and noise. The fixed speed wind generator will not produce harmonic current during the continuous operation; because there is no power electronic converter involved in the wind turbine.A variable speed wind turbine with a frequency converter will introduce harmonic voltage in the grid, because a frequency converter generates an imperfectly sinusoidal shaped current. Modern PWM frequency converters for variable speed wind turbines will typically operate with a switch frequency over 2kHz, and ideally noise will only be generated around integer multiples of switching frequency. As per relevant standards, the voltage harmonic distortion rate should no more than 2%.As shown in Fig 6, the voltage harmonic distortion rate wind farm is 1.44% which is within the permissible limits.

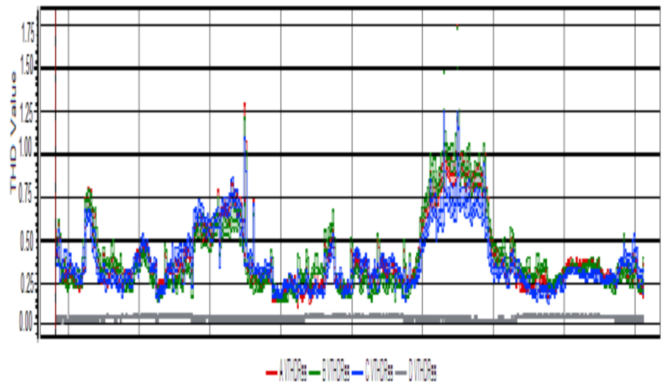

Fig 6. Recorded Total harmonic distortion

The measured data at the wind farms pertaining to various power quality issues are tabulated in Table 1

Table 1: Recorded power quality events at fixed and variable speed wind farms.

Si.No	Wind farms	No. of Transient events		No. of Sag events	No. of Swell events	No of Interruption events
		Impulsive	oscillatory			
1.	Fixed speed Induction generator wind farm	34	12	26	6	6
2.	Doubly fed induction generator wind farm	20	1	6	2	-
3.	Converter fed synchronous generator wind farm	24	8	10	4	-

From Table 1, it is observed that the numbers of impulse transients in all the three types of wind farms are high where as the transients of oscillatory nature comparatively negligible in doubly fed variable speed farm. The other events like sag and swell are the maximum in fixed speed generator and

minimum in variable speed generator. Interruption occurs only with fixed speed wind farm.
The data represented as a percentage of each event from the permissible limit by the standard as recorded by the Dranetz power quality analyzer is shown in Table 2 below.

Table 2: Compliance report from the Dranetz power quality analyzer Sag events

Magnitude Dips	10-100 msec	0.1-0.5 Sec	0.5-1 Sec	1-3 Sec	3-20 Sec	20-60 Sec	1-3 Min	>3 Min
0% - 10%	1(IG), 2(DFIG)	3(IG)	2(IG), 1(DFIG)	-	-	2(SG)	-	-
10%-15%	3(SG)	1(DFIG)	-	-	-	2(DFIG), 2(SG)		-
15%-30%	-	-	-	-	-	-	-	-
30%-60%	-	1(SG)	-	-	-	-	-	-
60%-90%	4(IG), 2(SG)	1(IG)	-	-	2(IG)	2(IG)	2(IG)	9(IG)

Swell event

Magnitude Dips	10-100 msec	0.1-0.5 Sec	0.5-1 Sec	1-3 Sec	3-20 Sec	20-60 Sec	1-3 Min	>3 Min
0% - 110%	2(DFIG)	2(SG)	-	-	-	-	-	-
110% - 120%	2(SG)	4(IG)	1(IG)	-	-	-	1(IG)	-
120% - 140%	-	-	-	-	-	-	-	-
140% - 160%	-	-	-	-	-	-	-	-
160% - 200%	-	-	-	-	-	-	-	-

Interruption event

Magnitude Dips	10-100 msec	0.1-0.5 Sec	0.5-1 Sec	1-3 Sec	3-20 Sec	20-60 Sec	1-3 Min	>3 Min
99%-100%	-	-	-	-	-	-	1(IG)	5(IG)

On analyzing the data, it is seen that the fixed speed wind farm alone generates nine sag with 60 to 90% voltage drop and five interruption events with duration of more than 3 minutes. Apart from this there are two more occasions where the sag is with 60 to 90% voltage drop lasting up to 3 seconds.
On analyzing the recorded data from the variable speed generator, it is seen that there is just one occasion where voltage drop is less than 10% and the duration less than 1 second. And two occasions with voltage drop lasing less than 100msec. Similarly, on another occasion voltage drop is up to 15% lasting less than 0.5 seconds. Voltage swell with 10% increase in voltage is recorded twice with a duration of less than 100msec. No event is recorded with regard to interruption or voltage sag and swell of larger magnitude or larger duration.
The events marked in red color are the ones which are much more than the permissible limits and hence indicates the non suitability and blue color column specifies the marginally suitable condition of the wind generator. The events between 10msec to 100msec are considered as momentary categories with 0 to 10% of voltage drops due to a sudden load injection and minor faults, 60 to 90% of voltage drops due to sever fault. The events that occur within 1min intervals are considered as temporary categories which are not a major cause of concern.
The power quality issues associated with the synchronous generator are neither as less as that of variable speed doubly fed induction generator nor as high as that associated with fixed speed generators.

Conclusion:
The scarcity in power generation is overcome to some extend by the wind power generation at Coimbatore district, Tamilnadu (India). However, the increases in the penetration of wind power into the Tamilnadu grid cause many power quality issues in the power system. In order to improve the stability, power quality and reliability of the turbines, the power quality monitoring at each wind farms is must. IEC 6100-21 standard specifies the requirements for the measurement and assessment of harmonics, voltage sag, voltage swell, flickers, and voltage drops of grid-connected wind turbines. Therefore, the power quality issues or events at the wind generators have to be within the specified limits. Power quality analyzers of different makes are installed at fixed and variable speed wind farms near the individual wind turbine and group control feeder at the substation. Number field trips are executed during the months of heavy wind flow. Data recorded by both meters are giving the same results.. From the recorded data' analysis, the following conclusions are drawn

1. Variable speed Wind farm with doubly fed induction generator is very superior to the other generators as it emits less number events.
2. Fixed speed wind farms are the ones which generate maximum number of events.
3. The Converter fed synchronous generator wind farm produce harmonics distortion within 2% which meets the standard requirement.

Reference

[1] Yang Ping, Yang Jinming, Zhang hao, et al. Development of New Hybrid (Solar-wind) Power system[J]. North China Electric Power,, (1): 24-28.2004

[2] Hu Wenjin, Wu Zhigang,Zhang Yao, et al. Analysis and Evaluation on the Electric Power Quality of the Wind Farm. Proceedings of the CSU2EPSA, 2009, 21(4): 82-87.

[3] Wu Xiaochao, Wu Jie, Yang Jinming, et al. Study and application of realtime power quality supervisory system for wind power plants. Computer Engineering and Design, 27(19): 3525- 3527. 2006

[4] Sun Yuanzhang, Wu Jun, Li Guojie. Influence Research of Wind Power Generation on Power Systems. Power System Technology, 31(20): 55-62. 2007

[5] Peng Mingzhi, Liu Yongqiang, Zhao Fuqiang, Design and Application of Electrical Energy Quality Monitoring System for Wind Power. Low Voltage Apparatus, (7): 45-48. 2013

[6] Li Yu, Fan Gaofeng, Li Qing, et al. The Impact of Dabancheng Wind Farm Integration on Power Quality of Xinjiang Power Grid[J]. Power System Technology, 31(6): 88-91.2007

[7] Poul Sørensen, Nicolaos Antonio Cutululis,, Torsten Lund, Anca D. Hansen, Troels Sørensen, Jesper Hjerrild, Martin Heyman Donovan, Leif Christensen, Henny Kræmer Nielsen, Power Quality Issues on Wind Power Installations in Denmark, Power Engineering Society General Meeting. IEEE,2007

[8] Ing. Mag. (FH) Robert Neumann, Eng. Jia Wei Hong Power Quality Monitoring for Wind Farms Distributech conference feb2009.

[9] Zhongquan An, Yongfeng Ren,Hanshan Li Analysis and Testing of Wind Farm Power Quality Inner Mongolia PP 2002 t0 2005 2011 IEEE.

[10] Wind Turbines—Part 21: Measurement and Assessment of Power Quality characteristics of Grid Connected Wind Turbines, IEC Std. 61400-21, 2008.

[11] Poul Sørensen and Peter Hauge Madsen, Risø, Denmark Anders Vikkelsø and K. Kølbæk Jensen, DEFU, Denmark K.A. Fathima, A.K. Unnikrishnan and Z.V. Lakaparampil "Power quality and integration of wind farms in weak grids in India" Risø National Laboratory, Roskilde April 2000.

[12] A.D.Thirumoorthy(TEDA), C.Chellamuthu RMK Engg college "Study on power quality issue of grid connected wind farm" www.cwet.res.in

[13] Akhmatov V. (2002), *Variable-speed wind turbines with doubly-fed induction generators. Part II: Power System Stability*. Wind Engineering, Vol. 26, No. 3, pp 171-188.

[14] R. Pena, J. C. Clare, and G. M. Asher, "Doubly fed induction generator using back-to back PWM converters and its application to variable-speed wind-energy generation," *IEE Proc. Electr. Power Appl.*, vol. 143, pp. 231–241, May 1996.

[15] B.V. Gorti, G.C. Alexander, R. Spée, "Power balance considerations for brushless doubly-fed machines," Department of Electrical & Computer Engineering, Oregon State University, Corvallis, OR 97331 USA, December 1 996.

[16] H. Bindner, "Power control for wind turbines in weak grids: Project summary," Risø-R-1 1 1 7(EN), 29 p. 1 999.

[17] M. Rosadi, S.M. mayeen, R. Takashahi, J. Tamura, Novel control design of variable speed PM wind generator considering grid code requirement, in: Proceedings of 15th International Conference on Electrical Machines and Systems (ICEMS 2012), Sapporo, Japan, Oct. 22-24, 2012.

[18] H. Wang, J. Su, C. Nayar, M. Ding, Control and interfacing of a grid-connected small-scale wind turbine generator, IEEE Transaction Energy Conversion 26 (2) 428-434.2011

[19] P. Sørensen, Methods for Calculation of the Flicker Contributions from Wind Turbines report Risø – I – 939 (EN), Roskilde, Denmark, December 1995.

[20] Larsson, A.:Flicker emission of wind turbines during continuous operation. IEEE Trans Energy Convers, 17 (1),114–8 (2002).