Wind Power System Harmonics Analysis Using DigSILENT

MODU ABBA GANA[1], ADAM BUKAR[2]
[1, 2] *Department of Electrical and Electronics Engineering, University of Maiduguri, Borno State, Nigeria*

Abstract- This paper presents harmonics analysis of wind power system in DigSILENT environment under linear and nonlinear loads scenarios. Harmonics analysis of wind farm system is essential to study the behavior of equipment connected in the non-sinusoidal system environment. Wind turbine connected to synchronous generator is modelled using Digsilent simulation software to analyze the said issues where Synchronous Var Compensator (SVC) is introduced as an active voltage and reactive power supporter to increase the power system stability. Simulation models are developed for linear and nonlinear loads and analysis of the voltage and current harmonics is performed for these loads individually with and without SVC. Results obtained showed that, introduction of SVC significantly mitigate the harmonics issues.

Indexed Terms- Synchronous Generator, DigSILENT, Wind Turbine Generator, Synchronous Var Compensator, Harmonics Analysis.

I. INTRODUCTION

It is the objective of the electric utility to supply its customers with a sinusoidal voltage of fairly constant magnitude and frequency. The generators that produce the electric generate a very close approximation to a sinusoidal signal. However, there are loads and devices on the system which have nonlinear characteristics and result in harmonics distortion of both the voltage and current signals. As more nonlinear loads are introduced within a facility, these waveforms get more distorted. In recent years wind power generation has experienced a very fast development in the whole world. As the wind power penetration into the grid is increasing quickly, the influence of wind turbine on the power quality is becoming an important issue. Induction generator is more attractive than synchronous generator for wind turbines due to their robust construction, low cost, low maintenance, long life and low power to weight ratio. Wind power penetration is the impact on power system stability. To facilitate the investigation of the impact of a wind farm on the dynamics of the power system to which it is connected, an adequate model is required. In order to avoid the necessity of developing a detailed model of a wind farm with tens or hundreds of wind turbines and their interconnections, aggregated wind farm models are needed [1]. Two of the main requirements are reactive power control in normal operation conditions [2] and fault ride-through capability during fault conditions [3].

The main purpose of normal operation requirements is to maintain the voltage between admissible limits both for security and power quality purposes. Since reactive power cannot be transmitted over long distances, it has to be provided locally. Therefore, in grid connection specifications, wind farms are generally required to contribute to reactive power (and sometimes voltage) control. Concerning fault condition requirements, they are aimed at avoiding as much as possible the loss of generation capacity in case of a fault in the transmission grid.

There are a number of possible interconnection structures for wind farms and thus it is not possible to cover every type of network configuration, load, and interconnection point of the wind farm. Frequently wind parks are connected to weak systems, as they are typically located far from major load centres and central generation. This reflects itself in the short circuit ratio (SCR) of the interconnection. For weak systems the SCR will usually be less than 6 having over speed of generator [4]. Reactive power is the most important aspect in today's condition. Reactive power consumption in a Wind farm is mainly due to the use of induction generators for energy conversion. The basic principle of induction generator is that they consume reactive power in order to generate real power. The magnetizing currents drawn by step up transformers also contribute to reactive power consumption to some extent. This reactive power consumption leads to increased T & D losses, poor voltage profile over loading of T & D equipment and blocked capacity and over loading and reduction in life of T & D equipment [5]. With the rapid increase in penetration of wind power in power grids, tripping of many turbines in a large wind farm during grid faults may begin to influence the overall power system stability [6].

Considering the increasing share of wind generation interfaced to grid, it is necessary to study an overall prospective on various types of existing wind generator systems and possible generator configuration, critical power quality issues, problems related with grid connections [7]. Use of more intelligent controller for SVC and its interface to large power systems addressing various issues such as security, stability, and voltage profile improvement and power quality [8].

In this paper a wind turbine fed synchronous generator is modelled using DigSILENT and harmonics for linear load & nonlinear load, are analysed. The SVC used as a device for mitigate these problems and simulation results prove that SVC is an effective means to mitigate these problems during continuous operation of grid connected wind turbine.

II. POWER QUALITY INDICES UNDER HARMONIC DISTORTION

Harmonic indices have been developed to assess the service quality of a power system with respect to the harmonic distortion levels. These indices are measures of the effective value of a waveform and can be applied to both the current and the voltage. The IEEE-519 document has set limits on the level of allowable harmonics (IEEE Standard 519-1992, 1992). Several indices are available for harmonic analysis; however, the most commonly used is the total harmonic distortion (THD). Mathematical formulations of (THD) for voltage and current are given in equations (1) and (2) respectively: [11]

$$THD_V = \frac{\sqrt{\sum_{h=2}^{\infty} {V_h}^2}}{V_1} \tag{1}$$

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} {I_h}^2}}{I_1} \tag{2}$$

Where,
V_1 and $I_1$are the RMS value of the fundamental.
Vh and Ih are the RMS value of the h-order harmonic component.

The study system Wind farm has been installed with a total capacity of 15 MW and constituted by 6 wind turbines. Rotor diameters and hub heights of wind turbines are 90 m. and 80 m. respectively. The nominal power of each turbine is 3 MW manufactured by Vestas V90. So far wind farm has been effectively worked and produced electrical energy.

In wind turbines of installed wind farm, three-phase wound rotor synchronous generator is used. [9 - 10] Each wind turbine generator has been connected to its own 0.69/34.5 kV star-delta connected transformer. The neutral point of the transformer is grounded to diminish the third harmonic voltages. These generators are connected to 154 kV power lines via 154/ 34.5 kV, 15 MVA transformers. The substation also ensures that the electric power generated from wind is delivered to the transmission line at constant voltage level of 154 kV and 50Hz.

III. MATERIALS AND METHOD

Modelling simulation of wind farm system including synchronous generator

A wind farm typically consists of a large number of individual wind turbine generators (WTGs) connected by an internal electrical network. To study the impact of wind farms on the dynamics of the power system, an important issue is to develop appropriate wind farm models to represent the dynamics of many individual WTGs. The major issues considered for the work for grid connected WTGs, equipped with synchronous generators are harmonics.

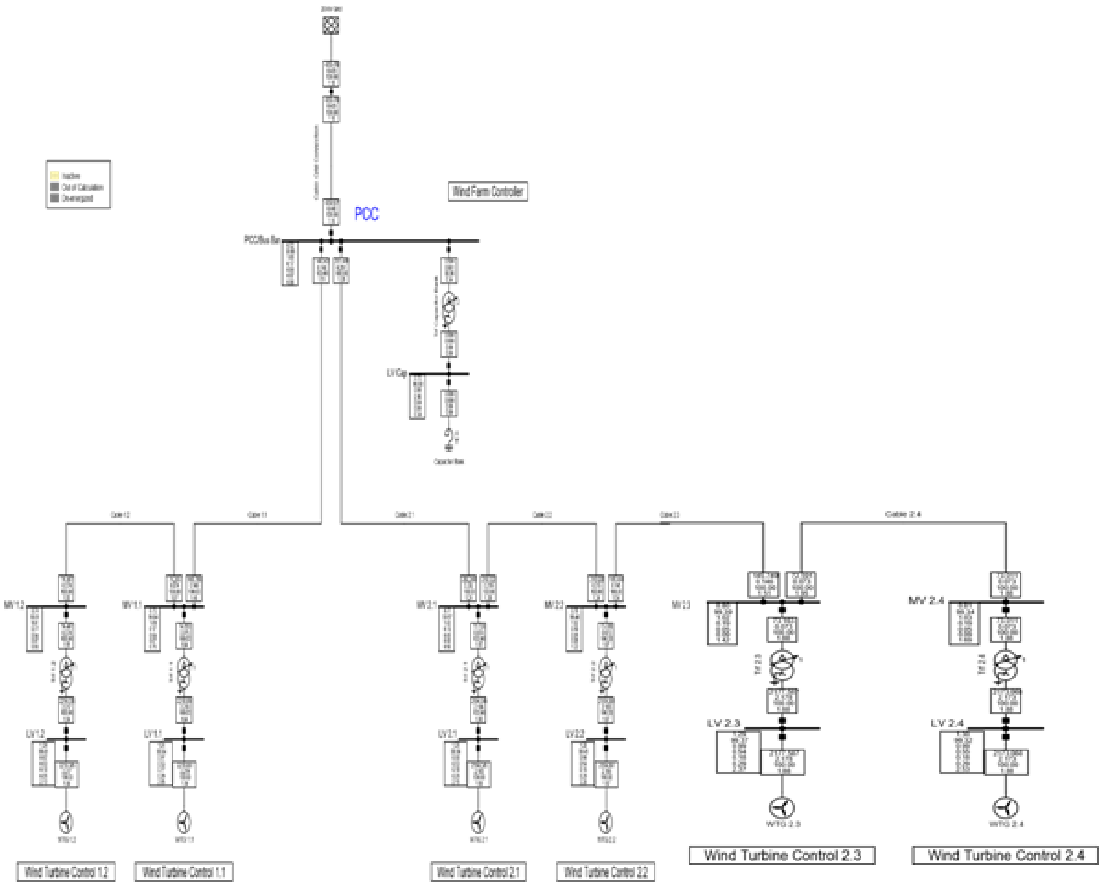

Fig.1. 15 kW Wind farm Model in DigSILENT Environment

The model is developed and compared by simulation studies in the DigSILENT environment under different wind velocity and fluctuation conditions.

In this case study, large scale wind farm with synchronous generator having capacity 15 MW is connected to 33/132 kV substation to 220 kV electric grid system is modelled by DigSILENT as shown in Figure 1.

IV. HARMONICS ANALYSIS

Harmonics are sinusoidal voltages or currents that are integer multiples of the fundamental frequency. It is the objective of the electric utility to supply its customers with a sinusoidal voltage of fairly constant magnitude and frequency. The generators that produce the electric power generate a very close approximation to a sinusoidal signal. However, there are loads and devices on the system which have nonlinear characteristics and result in harmonic distortion of both the voltage and current signals. As more nonlinear loads are introduced within a facility, these waveforms get more distorted. The objective of this paper is to consider the effect of linear and nonlinear loads on the utility voltage and current harmonics. Some of the commonly used loads in the wind farm systems are modelled in DigSILENT, by considering the voltage and current waveforms. Harmonic analysis of complete wind farm system is performed.[12 - 13]

S/No	Parameter	THD (%) With Linear load			THD (%) With nonlinear load		
		hase A	Phase B	hase C	hase A	hase B	hase C
1	Voltage	3.85 %	5.77 %	7.78 %	11.53 %	10.78 %	13.63 %
2	Current	6.04 %	6.31 %	4.04 %	8.98 %	10.62 %	12.05 %

Table I: Results of THD of Currents and Voltages of Linear and Nonlinear Loads

Table I indicates the simulated results of THDs of Individual Currents and Voltages of Linear and nonlinear Loads.

V. MITIGATION OF HARMONICS ISSUES BY USING SVC

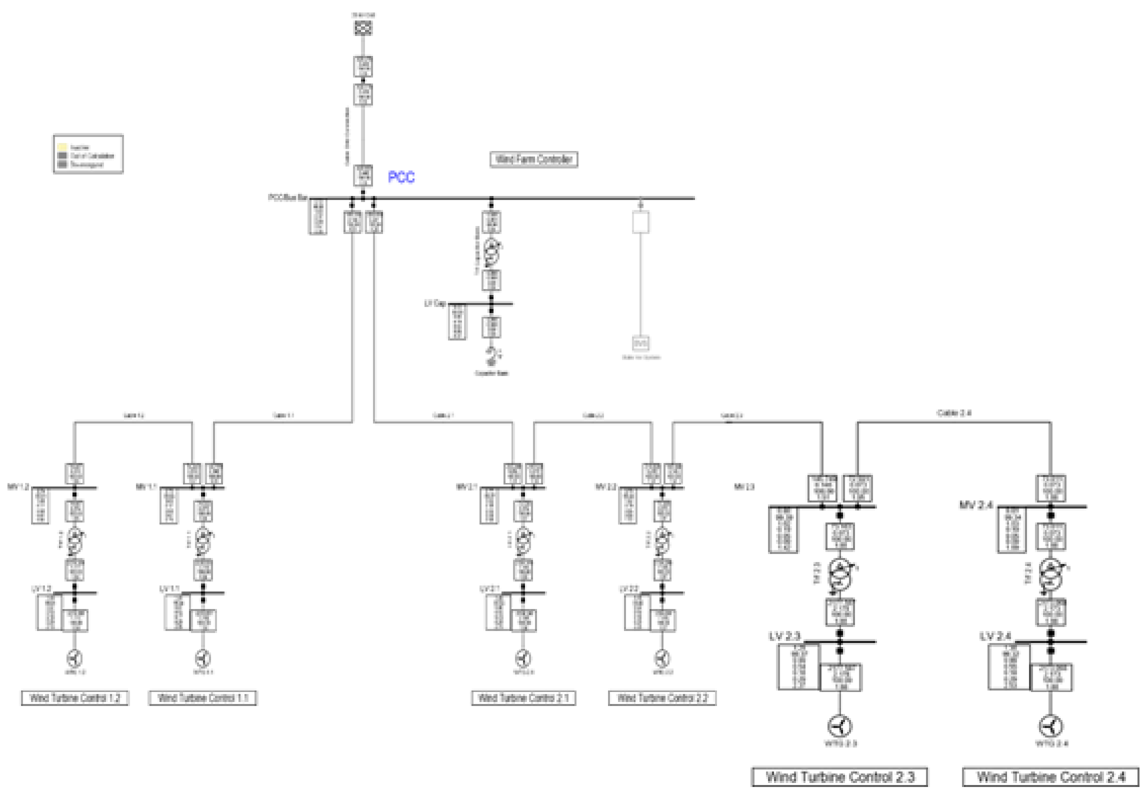

Fig. 2. Study System connected with SVC

The Static Var Compensator (SVC) is a shunt connected reactive compensation equipment which is capable of generating and/or absorbing reactive power whose output can be varied so as to maintain control of specific parameters of the electric power system. It consists of VSC connected in shunt to a bus through a coupling transform. The static compensators are devices with the ability to both generate and absorb reactive and active power, but the most common applications are in reactive power exchange between the AC system and the compensator. The compensator control is achieved by small variations in the switching angle of the semiconductor devices, so that the fundamental component of the voltage produced by the inverter is forced to lag or lead the AC system voltage by a few degrees. This causes active power to flow into or out of the inverter, modifying the value of the DC capacitor voltage, and consequently the magnitude of the inverter terminal voltage and the resultant reactive power. If the developed voltage is higher than system voltage the SVC will supply reactive power like a rotating synchronous compensator and improve the voltage and conversely if lower it will remove reactive power. Figure 2 indicates the study system wind farm with Synchronous generator connected to the grid with SVC is modelled.

According to the guidelines IEC 61400-21 or IEEE STD 519-1992 harmonic measurements are not required for fixed speed wind turbines where the induction generator is directly connected to the grid. Harmonic measurements are required only for variable speed turbines with electronic power converter. The limits of VTHD for 132 kV systems are having voltage level greater than 69 kV is 5.0 %

Table II Mitigation of THDs of Voltages and current of Linear Loads by Using SVC

S/No.	Parameter	THD (%) With SVC			THD (%) Without SVC		
		Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
1	Voltage	2.86 %	1.96 %	2.41 %	6.04 %	6.31 %	4.04 %
2	Current	3.03 %	2.25 %	2.71 %	3.85 %	5.77 %	7.78 %

Table III: Mitigation of THDs of Voltages and current of Nonlinear Load by Using SVC

S/No.	Parameter	THD (%) With SVC			THD (%) Without SVC		
		Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
1	Voltage	3.00 %	2.72 %	1.98 &	8.98 %	10.62 %	12.05 %
2	Current	2.31 %	2.90 %	1.67 %	11.53 %	10.78 %	13.63 %

CONCLUSION

This paper has investigated the application of SVC to wind farm equipped with Synchronous Generators for analysis of voltage and current harmonics of linear and nonlinear loads individually. Simulation on model of large-scale wind farm is designed in DigSILENT software to study the harmonics mitigation using SVC. Wind turbine connected to synchronous generator is modelled using DigSILENT simulation software to analyze the said issues where SVC is introduced as an active voltage and reactive power supporter to mitigate the harmonics issues. The results obtained clearly showed that, introduction of synchronous Var compensator has significantly improved the performance of the system as both the voltage and current harmonics has reduced after the introduction of SVC.

REFERENCES

[1] Slootweg J. G. and KlingW. L., "Modelling of Large Wind Farms in Power System Simulations", Paper published in IEEE Conference, 23(7) PP. 503-508, 2002.

[2] Caramia, P., Carpinelli, G., Rossi, F., and Verde, P. "Probabilistic iterative harmonic analysis of power systems"IIEE Proceedings: Generation, Transmission and Distribution, 141(4), PP. 234 – 245, 1994.

[3] Carpinelli, G., Esposito, T., Varilone, P., & Verde, P. Firstorder probabilistic harmonic power flow. IEE Proceedings - Generation, Transmission and Distribution, 148(6), PP. 534 – 541, 2001

[4] Methodology for the Actualization and Systematization of the Legal and Economic Frame of Special Regime Power Production Activity (in Spanish) Spanish Royal Decree, 2004, RD 436/2004.

[5] David O. and Franc D. "Voltage Sag Response Requirements of Wind Power Facilities" Operation Procedure (in Spanish) Spanish System Operator (REE), 2006.

[6] Mazen Abdel- Salam, Adel Ahmed and Mahmoud Mahrous, "Steady- state and transient analyses of wind farm connected to an electric grid with varying stiffness", Proceedings of the 14th International Middle East Power Systems Conference, Cairo University, Egypt, Dec. 19-21, 2010 PP. 203-208, 2010.

[7] B. Venkatesh, "Power Quality issues and Grid interfacing of wind Electric Generators and Design of an Optimal reactive Power Compensation System for Wind farms"

[8] Kadam D. P. and Kushare B. E. "Dynamic Behaviour of Large-Scale Wind Farm" International Journal of Electrical Engineering. (5)6, PP. 757-764, 2012.

[9] Kadam D. P. and Kushare B. E. "Overview of Different Wind generator Systems and their comparisons", International Journal of Engineering Science & Advanced Technology, 2 (4) PP. 1076-1081, 2012.

[10] S. M. Muyeen, Mohammad Abdul Mannan, Mohammed. Hasan Ali, Rion Takahashi, Toshiaki Murata and Junji Tamura, "Stabilization of Grid Connected Wind Generator by STATCOM", Paper published in IEEE PEDS Conference, PP. 1584-1588, 2005.

[11] Emanuel, A. E.,Janczak, J., Pileggi,D. J., Gulachenski, E. M., Root, C. E., Breen, M. and Gentile, T. J. "Voltage distortion in distribution feeders with nonlinear loads" IEEE Transactions on Power Delivery, 9(1). PP 206 – 213, 1994

[12] Bagheri, P., Xu, W. and Ding, T."A Distributed Filtering Scheme to Mitigate Harmonics in Residential Distribution Systems" IEEE Transactions on Power Delivery, 31(2). PP 324 – 335, 2016

[13] Barros, J., Diego, R. I. and De Apraiz, M. "A discussion of new requirements for measurement of harmonic distortion in modern power supply systems" IEEE Transactions on Instrumentation and Measurement, 62(8). PP 123 – 132,2013