Power Quality Enhancement of Grid Integrated Wind based AC Microgrid using DSTATCOM

ISSN (e) 2520-7393
ISSN (p) 2521-5027
Received on 25th Aug 2020
Revised on 20th Sept, 2020
www.estirj.com

Mujahid A. Shaikh[1], Mansoor A. Soomro[2], Farhan A. Shaikh[3], Z.A Shahahani[4]

[1,2,3,4] *Department of Electrical Engineering, IICT, Mehran University of Engineering Sciences and Technology*

Abstract: Microgrid system that links many distributed power generations into a single network services partially or fully the energy demands of users provides advantages of lesser energy costs, increased efficiency, better environmental performance and local power reliability. The increase of wind based local energy generation with latest technologies, especially; battery energy storage system has been significantly increased. Still, the power quality and voltage regulation lag behind this progress, creating multiple power quality problems for end users. This white paper inclusively focuses on mitigating power quality issues in wind based microgrids due to vulnerable nature of wind and integration of wind power into grid system. When wind power is added to grid, it affects the performance of existing system. In this paper, VSC based DSTATCOM with battery energy storage is introduced as a power quality enhancing technique for grid tied wind based microgrid. The PLL based PI controllers are used for fast switching of IGBTs. The proposed strategy mainly relies on reactive power exchange for loads and wind energy system. Through this method, distribution system will be able to securely manage the stability and resiliency. The proposed methodology is simulated in using MATLAB/Simulink software. The proposed technique has relatively high switching response against faulty operation and higher accuracy.

Keywords: Microgrid, DSTATCOM, BESS, PI controller, PLL, IGBTs.

1. Introduction

Over the last decades, globally, the wind energy generation has increased very fast; and manifested to be the rapidly growing renewable energy technology and a principal competitor to the conventional sources of energy. This trend has greatly increased due to being environment friendly and lesser energy costs [1]. By establishing a zero emissive power system before 2050, we are likely to meet our goal of climate change [2]. Generation by wind has become the most familiar energy source in the power system these days [3]. A strong growth has been noticed since last few decades. Worldwide, 817 GW is expected to be generated at the end of 2021; this will share 12% of world's electricity [4]. Wind generation market is led by Denmark with 40% of its generation through wind followed by Portugal, Ireland, Spain, Uruguay and Cyprus with 20%, and Germany 16% [5].

Due to being widely used in distributed generation and having local availability, the renewable energy sources have introduced the concept of microgrids. The microgrid is basically a localized small-scale power system, including distributed generation, energy storage devices and load. The main application of microgrid is to provide the continuous power to remote societies during an outage of indefinite duration. The microgrid technology has been developed very fast in recent years with the trend of the integration of renewable resources and distributed generation with existing systems [6]. Microgrid offers considerable advantages such as least harmful impacts on environment, increasing energy efficiency and increasing quality of power. The microgrid operates in both grid-connected and islanded operation modes and they usually include different distributed generation sources such as wind, solar, hydel, bio mass and many others [7]. Microgrids with wind energy generation mostly use doubly feed induction generator, DFIGs with speed sensitive turbines [8]. DFIGs offers certain advantages such as, low converter capability, high efficiency and ease of controllability as this can operate under variable speed near their optimal turbine efficiency over wide range of wind speed [9]. On the other side, the DFIGs are sensitive to voltage variations [10]. When dealing with grid-connected mode of microgrid, there remains a problem of voltage instability all the time; as the speed of wind is not same through the day [11]. The important power quality problems, when integrating wind turbines with utility or main grid are voltage dip/rise, harmonics, flickers and poor power factor [12]. Routinely, the power system is subjected to variety of complexities due to variation in wind speed and non-linearity of load. These variations create problems of instability for power system, particularly, the voltage instability. The root cause of this voltage instability is variation in wind speed [13]. These variations affect the quality of power and create faulty operation. Voltage dips, harmonic distortion and flickers have been reported as the most common power quality problem experienced in

Corresponding author Email address*: mujahidali.shaikh@yahoo.com*

industrial, commercial, and residential sectors. These quality problems have created serious challenges for utility operators. Each year millions of dollars are spent to attain stable operation [14]. Moreover, due to voltage sags, rotor current also increases in doubly feed induction generators (DFIGs) at wind farms that results in extra heating and life expectancy [15]. The electric power system of these days is more complex in network and is more sensitive to distortions. The increasing use of sensitive loads i.e., semiconductor-based loads have increased the sensitivity of power system and has created increased challenges of fast, secure, accurate and extending control to enhance the system's working capability. In the present power delivery environment, both end-users and network operators have become increasingly concerned about the power quality. Because of an incredible increase in micro technology and power electronic appliances, the distribution network is highly relying on swing in voltage and frequency. To get neat and tidy power, controlling techniques are required that should be be installed in power system. The best solution in this regard is provided by flexible ac transmission system, FACTS controllers [16]. FACTS controllers regulate the voltage, power flow and compensate reactive power either separately or in grouped with other devices. The FACTS controllers provide best solution against faults occurring on grid side [17]. FACTS Controllers counter balance the reactive power drawn by induction generators for magnetization [18]. They provide continuous power to load, thus improving reliability during disturbances. FACTS devices are also best suited for power factor correction [19]. L. Lei and W. Sheng [20] have used STATCOM with Lithium battery and super capacitor hybrid battery to enhance power quality of wind-based Distribution system. They have used Squirrel Cage Induction Generator, SCIG for generation. In this work, SCIG could not extract maximum power when wind was slower. Amen and Djamel [21] have proposed unified power flow controller, UPFC for power flow control through transmission lines. UPFC is a costlier technique hence finds rare application. Mohanty and M. Vishwanada [22] used Fuzzy controller based UPFC for compensation in Hybrid Wind Diesel System. They used SCIG. X. She and Huang [23] used STATCOM for voltage conversion and power transfer in Distribution System. Here they used STATCOM without Battery system. They could not get satisfactory results. Bhattachatjee and Roy [24] used Fuzzy Logic based technique for DSTATCOM. It improved the power factor of constant speed wind system. S. Arya and B. Singh, R. [25] used DSTATCOM to overcome problem of voltage regulation. They have used the proposed technique to draw load currents. These values of currents they used as reference currents for DSTATCOM. This method was used for mitigating problems of reactive power imbalance, harmonics content and load unbalance. Mahela and A. Shaik [26] have used DSTATCOM for quick control of reactive power, frequency, harmonics, and flickers in distribution network. In [25] and [26] battery Energy system can be applied with DSTATCOM to effectively control reactive and active power flow in case of fault. A. Nabisha and X. Felix Joseph [27] have proposed Voltage Source Inverter, VSI and Voltage-Oriented controls to reduce harmonic currents and voltages for Grid connected Wind Energy System. He has used Self-Excited Induction Generators, SEIG. It improved power quality but the SEIG is dependent on system to which it is connected. In case of faults, this technique is not supposed to work effectively. Gelu Gurguiatu [28] has introduced indirect current technique to get reference signal for Insulated Gate Bipolar Junction Transistor, IGBT. Switching speed of proposed technique is not too much high for IGBTs. In this paper, DSTATCOM is introduced with batter energy storage system, BESS using PLL based PI controller technique for fast switching of IGBTs. This technique has faster response and relatively high accuracy. This enhances quality of power in distribution network. It also controls active and reactive power. The proposed method serves objectives of distortion free supply, increased reliability and increased supply security. It creates budgetary load on the supplier and user.

2. **Grid integration and related PQ problems**

The typical microgrid has capability of operating in both grid-connected and stand-alone modes. The microgrid interconnection with main grid provides advantage of effective utilization of generated power. Traditionally, the microgrid is constructed with additional power. This additional power can be sent back to the grid for revenue streams hence it provides ancillary services for trading between the microgrid and the main grid [33]. Connecting ac microgrid to a utility grid provides stable operation but only when the wind based microgrid acts as a stable source to the utility grid. The wind speed defines the amount of electricity generation by a wind turbine, more the wind speed, more the power is generated; because higher wind makes blades to move faster [29]. Faster rotation converts more mechanical power into electrical power. Since the wind speed is not constant, it is varying all time. Hence the power output is not same all times. When wind turbines are integrated with utility grid, they produce varying power [30]. Owing to varying power, there is problem of voltage dip and voltage rise. Power electronics-based harmonics and flickers [31].

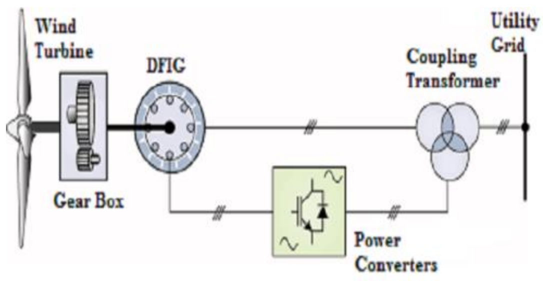


Fig.1 Microgrid integration with utility grid

During the severe voltage drop, the microgrid is switched to island operation mode. This brings immediate changes for both grids. When the connection is lost, the microgrid is assigned to provide power to island loads only and the utility grid experiences sudden load burden. This tripping insists the availability of both automatic and manual reconnection procedures at the PCC. The detail of power quality issues regarding grid integration is defined as below.

Voltage Dip/Sag, d: This is caused by initial start-up of wind turbine because initially they draw reactive power from grid. This produces a sudden inclination in voltage. The voltage dip is given as;

$$\text{Voltage Dip, d} = \frac{K\, S_n}{S_k} \quad (1)$$

Voltage Rise/Swell (u): This is caused by function of the turbine when wind speed is greater than normal speed.

$$\text{Voltage rise, } \Delta u = \frac{S_{max}(R\cos\emptyset - X\sin\emptyset)}{U^2} \quad (2)$$

Flicker: This is measure of frequent switching operation of wind turbine within specified period.

$$\text{Flicker, } P_{lt=C(\psi_k)\frac{S_n}{S_k}} \quad (3)$$

Harmonics: This is associated with power converters used with wind turbine.

The total harmonic voltage distortion is expressed as;

$$V_{THD=}\sum_{h=2}^{40}\frac{Vn^2}{V1}100 \quad (4)$$

The total harmonic current distortion is expressed as;

$$I_{THD=}\sum_{h=2}^{40}\frac{I_n}{I1}100 \quad (5)$$

3. Grid integration specifications

Grid coordination is done under strict rules and regulations. There are several standards specifying various aspects of grid interconnection. Arguably, the most well-known is IEEE p1547. This standard defines specification for interconnecting wind energy system with existing electric power system. IEEE standard 1547.2 of 1547 limits the power quality issues of wind system to acceptable limits for stable operation. The acceptable limit for various power quality problems is given below table no.1;

1) The acceptable lower and upper limit to voltage dip and rise is < 3% and < 2% respectively [32].
2) The acceptable limit to flicker coefficient is ≤ 0.4% for two-hour time [32].
3) The acceptable limit to harmonics distortion for 11kV and 132kV is < 4% and < 2.5% respectively [32].
4) The acceptable limit to grid frequency in lower and upper case is 47.5Hz and 51.5Hz respectively [32].
5) In case of fault, the wind turbine should sustain 30% voltage dip in ordinary working condition for 100milli seconds IEEE p1547.2.

4. Modeling of proposed system

This paper presents an inclusive study and application of DSTATCOM with battery energy storage system, BESS for power quality improvement of grid connected wind farm. This technique incorporates PLL based PI controller for IGBTs. This technique provides fast switching response during faulty operation. It also provides high accuracy method compared to other FACTS devices. The ultimate goal of this research is to maintain the synchronism between grid and users. This technique counter balances the active and reactive powers at PCC. It synchronizes the angle of voltage and current at variable wind speeds.

4.1 Model Description

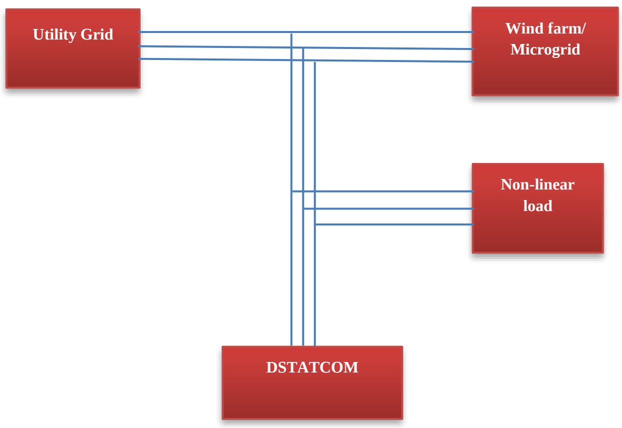


Fig. 2 Description of proposed model

In the proposed model, wind farm is integrated with main grid through bus bars at PCC. These two sources are now acting as single source. The load and proposed DSTATCOM are connected at PCC. The power generated from wind turbine on microgrid is calculated as; since the total kinetic energy of wind is not converted into mechanical power, the fraction of power is converted which is given as;

$$P_{mech} = C_P P_{wind} \quad (6)$$

Here,

C_p is coefficient of mechanical power that depends upon condition and type of wind turbine.

Mechanical power in terms of wind speed ratio and pitch angle is;

$$P_{mech} = \frac{1}{2}\Pi R^2 V^3 \min C_p \quad (7)$$

Here,

R is the radius of blade in meters.

4.2 **Model Detail**

The system is consisting of two power systems. One is utility grid and other is microgrid. These are coupled at PCC under strict control strategies. The utility grid has constant power while the microgrid has variable power due wind variation. When integrated, it is mandatory for both systems to have same voltage level.

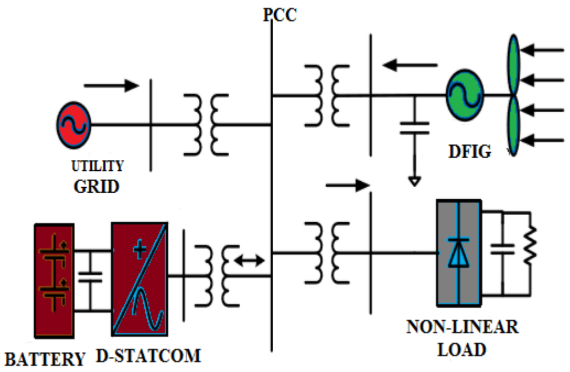


Fig.3 Wind energy system connected with DSTATCOM

When utility grid is connected to microgrid and non-linear loads, the power quality is affected as the wind farm is not generating constant power and also due to non-linear load. Therefore, an external device is provided to counter balance the state of synchronism at PCC. This work is simulated in MATLAB/SIMULINK software.

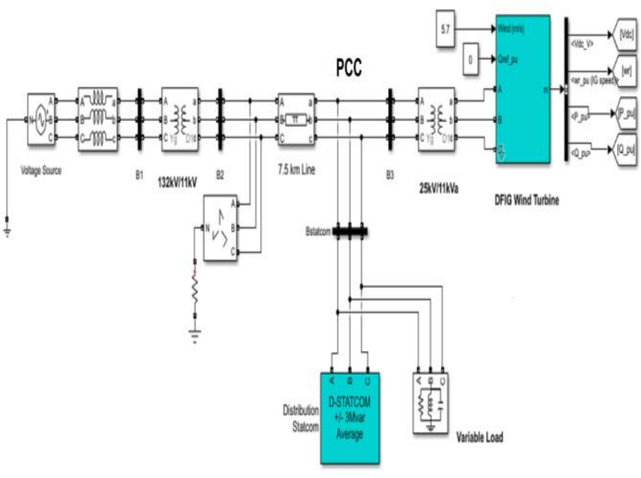


Fig. 4 Proposed model

The bus B2 represents grid bus and B3 represents wind system. These are coupled at PCC. The model parameters are shown in table-1.

Table.1 Model Parameter

S. No.	Parameter	Rating
1	Grid	3-Phase, 132/11kV, 50Hz
2	Wind system	3 MW (2x1.5 MW), 11kV, 50 Hz
3	Load	Non-linear, 500Kw
4	DSTATCOM	3MVAR, Average Model Inverter Rating DC Interface Voltage=1200V
5	IGBT Rating	Collector Voltage = 1200V, Forward Current =50 A, Gate voltage = 20 V, Power dissipation =310 W
6	Line series Inductance	0.05 Mh

The voltage level of utility grid is 132/11kV. Voltage level is stepped down to distribution level of 11kV. Wind Microgrid produces 575V which is stepped up to 11kV to get integrated with utility grid. In this model 3-phase, 3-wire system is assumed.

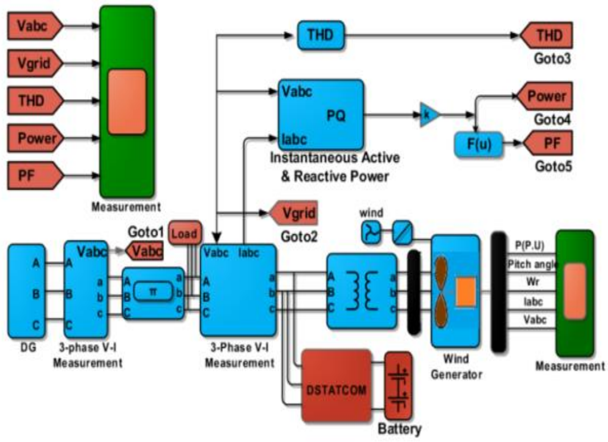


Fig.5 Integration of grid and wind farm

4.2.1 **DSTATCOM**

Distribution STATCOM is basically a parallel connected device that balances the bus voltage by counterbalancing the reactive power. This is used at L-V side of power system. In L-V system, it is used as voltage regulator. DSTATCOM finds major applications in distribution networks. It is also used widely with Microgrid systems [36].

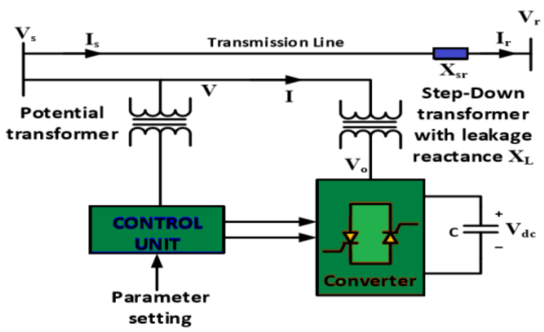


Fig.6 DSTATCOM model

In the fig. 4, DSTATCOM is connected in between main grid and wind turbines. It injects or absorbs reactive power at point where power quality problems are concentrated. The

DSTATCOM differs from other VAR compensators in the sense that beside voltage compensation it can be used for harmonics absorption, power factor improvement and unbalance load compensation [37]. The DSTATCOM has VSC based control system that provides voltage from energy storage system in accordance with control scheme. If the voltage at PCC and the voltage of converter are same the compensator will not inject or absorb the current from the system. If $V_{pcc} < V_D$, the compensator draws leading current and supplies VAR into system and if $V_{pcc} > V_D$, it draws lagging current and absorbs VAR from system. Here, V_{pcc} is voltages at PCC and V_D is DSTATCOM voltages.

4.2.1.1**VSC of DSTATCOM**

The voltage source converter, VSC of DSTATCOM is basically a converter that converts DC voltages of BESS into AC voltage. This AC voltage is fed to system through PCC. The output voltages of VSCs are in phase with system voltages at PCC. This is done with help of PI controller-based phase locked loop, PLL. The output of VSCs is injected to system via coupling transformer which is connected in parallel with distribution network. A suitable adjustment of phase angle and magnitude of DSTATCOM output allows an effective and fast exchange of powers between power system and proposed technique.

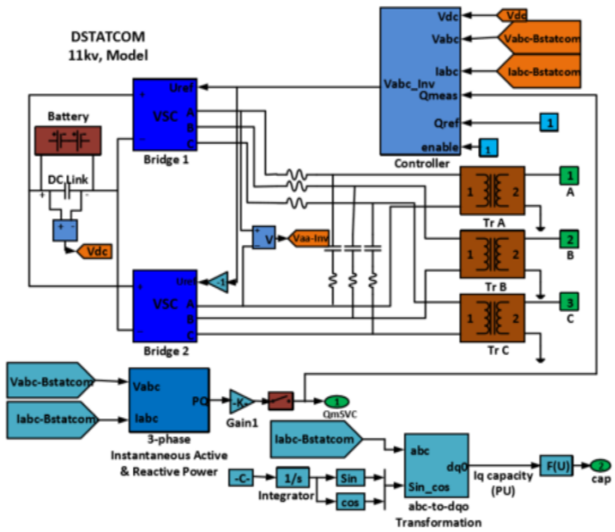
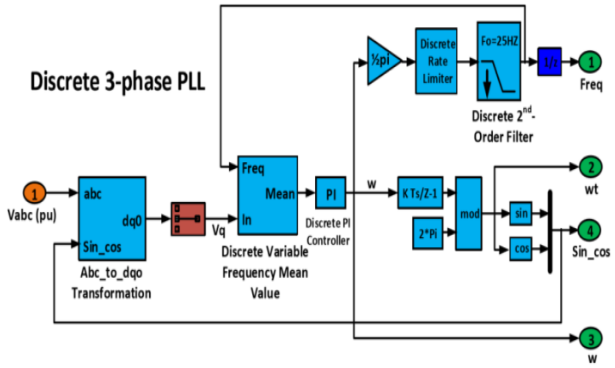


Fig.7 VSC of DSTATCOM

4.2.1.2 **PI controller based PLL**

The phase locked loop, PLL is used to synchronize the input signal of converter with system's parameters. The transformation block changes phase voltages into d-axis and q-axis voltages. The PI controller compares the d-axis and q-axis components of voltages and current with actual components, and generates an error signal. This error signal is fed to pulse width modulator, PWM. The PWM produces another signal that is used as gate signal for IGBT.

Fig.8 PI controller based PLL



4.2.1.3 **BESS of DSTATCOM**

The DSTATCOM consisting of IGBTs based VSC has capability of balancing distortion in the grid connected system. This has greater switching response for on-state voltage variations. Hence, this property of IGBT based DSTATCOM will protect system from getting isolated. The BESS in this regard is used as an energy storage element and this connection is a new method of storage where the batteries are exchanging energy with the utility grid [35]. A battery energy storage system is connected in shunt with DC interface Capacitor. In case of fault or sudden decrease in system voltage, it provides the voltage through coupling transformer. It has correspondingly fast response against voltage variation in the system. There are numerous energy storage methods incorporated with DSTATCOM, mainly are superconducting magnetic energy storage (SMES), Lead acid battery, super capacitors (SC) and battery energy storage system (BESS). In this paper, Lead Acid Battery system is proposed as it provides cost effective solution against Flickers. These are rechargeable and have longer life span [38]. The working chemical reaction of these batteries is as,

$$Pb + PbO_2 + 2H_2O_4 \leftrightarrow 2PbSO_4 + 2H_2O \qquad (8)$$

4.2.2 **Mathematical modeling of DSTATCOM**

In the figure below, DSTATCOM equivalent circuit is connected to distribution network at PCC via coupling transformer.

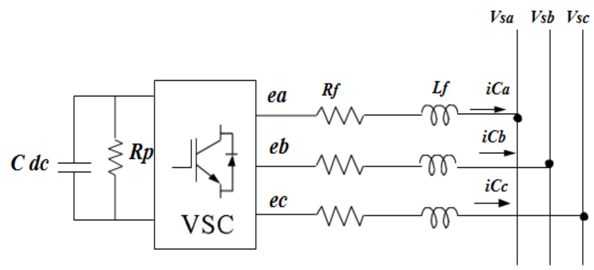


Fig. 9 Equivalent circuit of DSTATCOM

Here, e_a, e_b, e_c are output voltages of DSTATCOM,
I_a, i_b, i_c are output of DSTATCOM,
V_a, V_b, V_c are phase voltages at PCC,
R_f, L_f is reactance of interfacing inductor,
V_{dc}, I_{dc} are dc voltages and current of capacitor respectively,
C is capacitance of dc capacitor.

The relationship between phase voltages and battery voltages is given by,

$$v_a = \frac{1}{2} m_a V_{dc},\; v_b = \frac{1}{2} m_b V_{dc}, \qquad v_c = \frac{1}{2} m_c V_{dc},$$

m_a, m_b, m_c are modulation signals of phase *a*, *b*, *c*.

The power consumed on battery side is,

$$P_{dc} = V_{dc} C_{dc} \frac{d}{dt} V_{dc} + \frac{Vdc^2}{R_{dc}}, \tag{9}$$

Here,

$$\frac{d}{dt} V_{dc} = -\frac{1}{R_{dc} C_{dc}} V_{dc} + \frac{3}{2C_{dc}} M_d I_d, \tag{10}$$

$$\frac{d}{dt} I_d = -\frac{R}{L} I_d + \omega I_q - \frac{1}{2L} M_d V_{dc} + \frac{1}{L} E_d\,, \tag{11}$$

$$\frac{d}{dt} I_q = -\omega I_d - \frac{R}{L} I_q - \frac{1}{2L} M_q V_{dc}\,, \tag{12}$$

Here V_{dc}, I_d, and I_q are system variables, M_d, and M_q are the inputs, and V_{dc} and I_q are outputs, and E_d is a constant.

Now, the power delivered to system from DSTATCOM is,

$$P_{ac} = \frac{3}{2} E_d I_d, \tag{13}$$

Voltages injected by DSTATCOM at PCC is $\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} - \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$,

$$\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} - \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = (R_s + sL_s) \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}, \tag{14}$$

Here,

$$s = \frac{d}{dt},\; R_s = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix},\; L_s = \begin{bmatrix} L_s & M & M \\ M & L_s & M \\ M & M & L_s \end{bmatrix}$$

The above matrices of voltages and currents can be expressed to d-q reference form as,

$$\begin{bmatrix} e_d - v_d \\ e_q - v_q \\ e_0 - v_0 \end{bmatrix} = K_s \begin{bmatrix} e_a - v_a \\ e_b - v_b \\ e_c - v_c \end{bmatrix},\; \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = K_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}, \tag{15}$$

Here, K_s is Park's transformation and is expressed as,

$$K_s = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ \sin\theta & \sin(\theta - 2\pi/3) & \sin(\theta + 2\pi/3) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \tag{16}$$

When there is no neutral in the system, there will be no zero sequence components, hence above matrices are expressed as,

$$\begin{bmatrix} e_d \\ e_q \end{bmatrix} - \begin{bmatrix} v_d \\ v_q \end{bmatrix} = (R_s + sL_s) \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} -\omega & 0 \\ 0 & \omega \end{bmatrix} L'_s \begin{bmatrix} i_d \\ i_q \end{bmatrix}$$

Here,

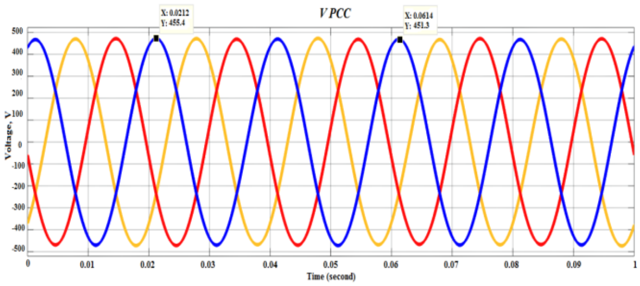
$$R_s = \begin{bmatrix} R_s & 0 \\ 0 & R_s \end{bmatrix},\; Ls' = \begin{bmatrix} Ls' & 0 \\ 0 & Ls' \end{bmatrix} = \begin{bmatrix} L_s - M & 0 \\ 0 & L_s - M \end{bmatrix}.$$

5. Results and discussion

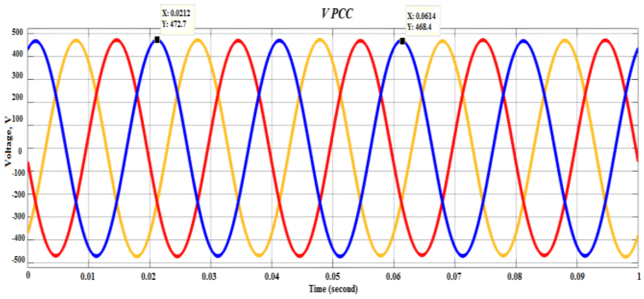
In this paper, DSATATCOM is applied to mitigate the power quality problems of wind based Microgrid when connected to main grid and to nonlinear loads at PCC. The system response is observed using MATLAB/SIMULINK software. The proposed technique provides active and reactive power exchange for non-linear loads and DFIGs. The system response against power quality issues in terms of voltage, power and harmonics is shown in following sections.

5.1 Voltage Variations

When wind based microgrid is connected to main grid, there occurs voltage unbalance at PCC due to variable power output of wind power system.



(a)



(b)

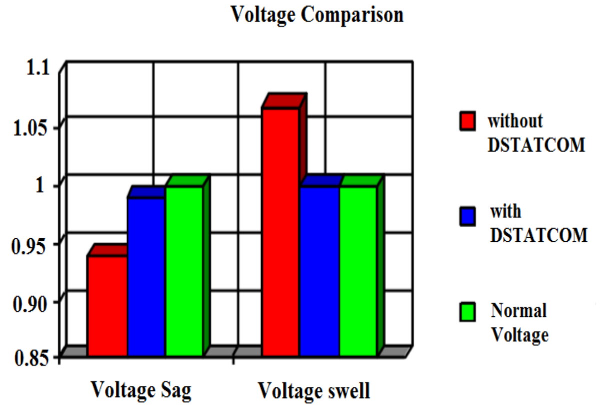
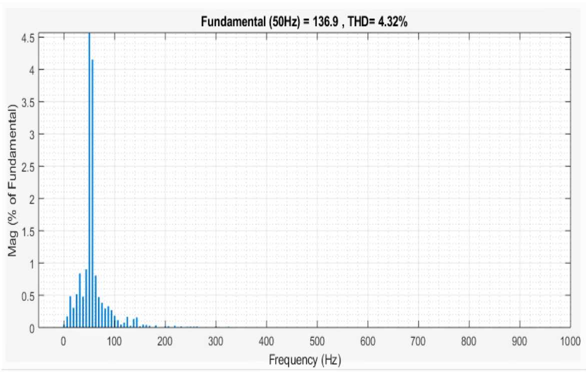


Fig.10 Comparison (a) without DSTATCOM (b) with DSTATCOM

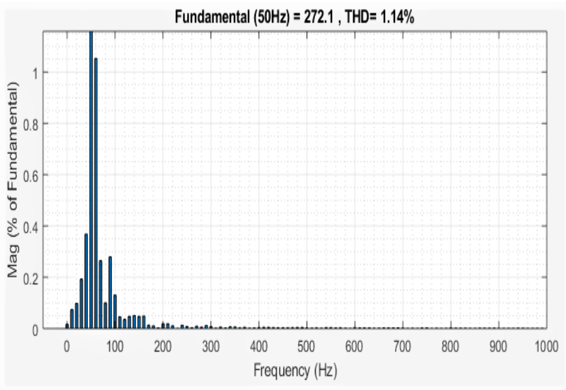
The variable voltages affected the power quality of system in terms of voltage variation. DSTATCOM regulated the voltage by injecting the reactive power at PCC. The comparison is shown in fig. the voltage regulation of DSTATCOM is 0.993 pu and 1.001 pu for sag and swell respectively.

5.2 **Total Harmonic Distortion, THD**

Total Harmonic Distortion is the measure of disturbance in the fundamental signal. The disturbance is caused by variable output power of wind system and non-linear load.



(a)



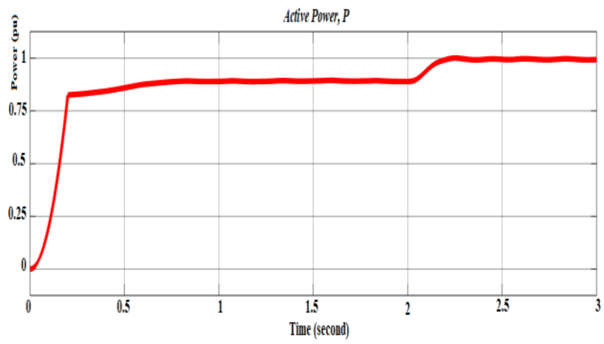
(b)

Fig.11 THD (a) without DSTATCOM (b) with DSTATCOM

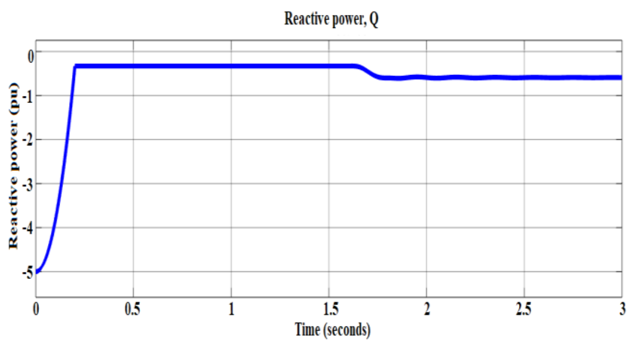
The THD recorded without DSTATCOM is 4.34% which is not acceptable according to IEC-61400-2; it should be ≤ 4% for 11kV system. The THD with DSTATCOM is recorded as 1.14%; this shows that DSTATCOM improved the harmonics at greater extent.

5.3 **Active and reactive power**

When wind system is connected to grid it absorbs the reactive power. As the inductive load is increased, the reactive power is reduced and when load is decreased reactive power is increased from normal values. The DSTATCOM in both situations perform equally well and provides power exchange at PCC.



(a)

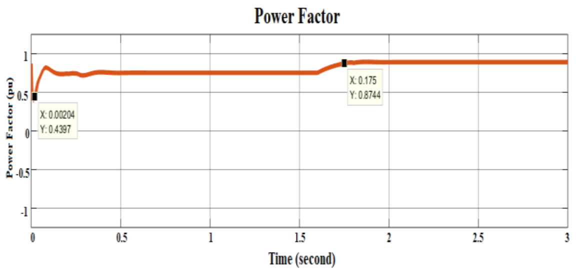


(b)

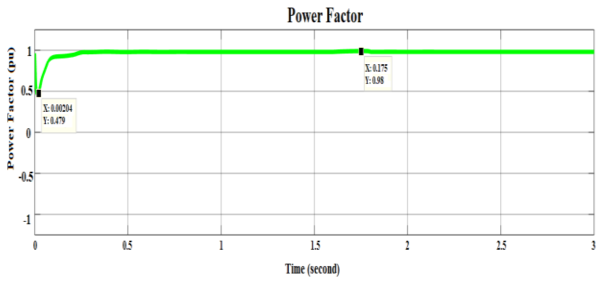
Fig.12 Active Power with DSTATCOM

5.4 **Power Factor**

Power factor is badly affected by inductive loads. In this model it is affected by DFIGs of the wind system. It is also affected by non-linearity of loads. The non-linear loads draw non-linear current wave form that disturbs the actual sinusoidal wave; resulting in poor power factor.



(a)



(b)

Fig.13 Power factor (a) without DSTATCOM (b) with DSTATCOM

Fig.13 clearly differentiates the role of DSTATCOM in power factor improvement. The power factor measured without DSTATCOM is 0.874 and with DSTATCOM is 0.980 pu.

6 Performance Analysis of DSTATCOM

Table.2 Analysis of DSTATCOM

Method	At PCC				THD%	Power Factor
	Sag	Swell	Fault	Normal		
Without DSTATCOM	0.94	1.07	0.77	1	4.34	0.874
With DSTATCOM	**0.989**	**1.001**	**0.97**	**1**	**1.14**	**0.980**

7. Conclusion

This paper presented the performance of DSTATCOM for grid connected wind based microgrid. This included power quality issues and their mitigation. The DSTATCOM effectively reduced the main power quality issues of voltage unbalance sag/swell, harmonics, and poor power factor using instant power exchange, P-Q theory. DFIGs don't have enough reactive power, so DSTATCOM is best suited for them. The proposed BESS system provided better controllability for active power under the events of voltage unbalance due to variable wind speeds. IGBTs based PLL and PI controllers are used for fast switching response. It is concluded from results and performance analysis that DSTATCOM with BESS can be effectively used to enhance the power quality of wind based Microgrid.

References

[1] E. Denny and M. O'Malley, "Wind generation, power system operation, and emissions reduction," IEEE Transactions on power systems, vol. 21, 2016.

[2] EWEA, "Powering Europe: wind energy and the electricity grid", 2019.

[3] Shoaib, M., Siddiqui, I., Rehman, S., Khan, S., & Alhems, L. M, "Assessment of wind energy potential using wind energy conversion system.'' Journal of Cleaner Production 2019.

[4] Akhilendra Singh Yadav, Aadesh Kumar Arya, "Microgrid with Renewable Energy Sources in Distribution Network", The Engineering Journal of Application & Scopes, Volume 1, Issue 2, July 2016.

[5] EWEA, "Wind Energy - The Facts " 2019.

[6] M. Suresh and Srinivas, "Power quality improvement in renewable energy interconnection grid at distribution", International journal, vol. 2, Issues 10, 2013.

[7] S K Khadem, M Basu and M Conlon, "Power Quality in Grid connected Renewable Energy Systems: Role of Custom Power Devices", ICREPQ, Spain, March 2010.

[8] M. Ali, A. youssef and A. Ali, "Comparative study of different pitch angle control strategies for DFIG based on wind energy conversion system", International Journal of Renewable Energy Research IJRER, vol. 9, no. 1, pp. 157–163, March 2019.

[9] W. Tang and Y. Chang, "Modeling of DFIG-based wind turbine for power system transient response analysis in rotor speed control timescale", IEEE Transaction on power systems, 2018.

[10] M. Ferrari, "GSC control strategy for harmonic voltage elimination of grid-connected DFIG wind turbine", 3rd International conference on Renewable Energy Research and applications ICRERA, pp. 185–191, Oct. 2014.

[11] R. Zamora and A. K. Srivastava, "Controls for microgrids with storage: Review, challenges, and research needs" Renew. Sustain. Energy Rev., vol. 14, no. 7, Sept. 2010.

[12] Muhammad A. Saqib, Ali Z. Saleem, "Power-quality issues and the need for reactive-power compensation in the grid integration of wind power", Renewable and Sustainable Energy Reviews 43, 2015.

[13] S. Kulkarni and P. shingara, "A review on power quality challenges in renewable energy grid integration", IJCET, vol. 6, no. 5, Oct 2016.

[14] Meraj Akhtar, Dr. Lini Mathew, "Cost Comparision of FACTS Devices for Industrial Application-A study", International Journal of Technical and Science, July 2016.

[15] P. Tourou, J. Chhor and C sourkounis, "Energy storage integration in DFIG-based wind energy conversion system for improved fault ride-through capability", 6th International conference on Renewable Energy Research and applications ICRERA, pp. 374–377, Nov. 2017.

[16] J. Urquizo, P. Singh, N. Kondrath, R. Hidalgo-Leon, and G. Soriano, "Using D-FACTS in microgrids for power quality improvement", IEEE Second Ecuador Technical Chapters Meeting (ETCM). IEEE, 2017.

[17] Dr. H Vennila, "Power Quality Improvement in Micro grids using Predictive Technique Based Static Compensator", IJIRST, Volume 3 | Issue 12 | May 2017.

[18] Foad H. Gandoman, Abdollah Ahmadi, "Review of FACTS technologies and applications for power quality in smart grids with renewable energy systems", Renewable and Sustainable Energy Reviews, January 2018.

[19] A. Sode-Yome, N. Mithulananthan, "A Comprehensive Comparison of FACTS Devices for Enhancing Static Voltage Stability", IEEE. March 2014.

[20] L. Lei, W. Sheng tie, and T. Guichon, "Grid power quality improvement with stator/Hess for wind turbine with squirrel-cage induction generator," in 2016 IEEE 11th Conference on Industrial Electronics and Applications (ICIEA). IEEE, 2016.

[21] L. Amen, L. Djamel, M. Zohra et al., "Influence of the wind farm integration on load flow and voltage in electrical power system," International Journal of Hydrogen Energy, vol. 41, 2016.

[22] A. Mohanty, M. Viswavandya, S. Mohanty, and D. Mishra, "Reactive power compensation in a stand-alone wind-diesel-tidal hybrid system by a fuzzy logic based upfc," Procedia Computer Science, vol. 57, 2015.

[23] X. She, A. Huang, F. Wang, and R. Burgos, "Wind energy system with integrated functions of active power transfer, reactive power compensation, and voltage conversion," IEEE Transactions on Industrial Electronics, vol. 60, no. 10, pp. 4512–4524, 2013.

[24] C. Bhattacharjee, A. Roy and B. Roy, "Improvement of availability load voltage for a constant speed WECS coupled with FUZZY-Controlled DSTATCOM", IEEE International Conference on Harmonics and Quality of Power, 2012, Hong Kong, China.

[25] S. Arya, B. Singh, R. Niwas and A. Chandra, "Power quality enhancement using DSTATCOM in distributed power generation system", IEEE Transaction on industrial application, November 2016.

[26] O. Mahela and A. Shaik, "Power quality improvement in distribution network using DSTATCOM with battery energy storage system," International Journal of Electrical Power & Energy Systems, vol. 83, pp. 229–240, 2016.

[27] A. Nabisha and X. Felix Joseph, "Power Quality Enhancement in Wind Energy Conversion System using PID Based D-STATCOM", Journal of Engineering and Applied Sciences, vol. 12, issue 14, pp. 3798-3802, 2017.

[28] Gelu Gurguiatu, "Power quality improvement using renewable energy", March 2015.

[29] P. Tourou, J. Chhor and C sourkounis, "Energy storage integration in DFIG-based wind energy conversion system for improved fault ride-through capability", 6th International conference on Renewable Energy Research and applications ICRERA, Nov. 2017.

[30] W. Tang and Y. Chang, "Modeling of DFIG-based wind turbine for power system transient response analysis in rotor speed control timescale", IEEE Transaction on power systems, 2018.

[31] A. Reis and J. Oliveira, "Physical concepts related to harmonics produced by wind turbines operation," IEEE Latin America Transactions, vol. 14, no. 4, pp. 1792–1799, 2016.

[32] S. Kulkarni and P. shingara, "A review on power quality challenges in renewable energy grid integration", IJCET, vol. 6, no. 5, Oct 2016.

[32] C. Reddy and P. Reddy, "A DSTATCOM-Control Scheme for Power Quality Improvement of Grid Connected Wind Energy System for Balanced and Unbalanced Nonlinear Loads", International Journal of Modern Engineering Research (IJMER), Vol.2, Issue.3, June 2012.

[33] Mehdi Bagheri, Venera NurmanovA, "Enhancing Power Quality in Microgrids With a New Online Control Strategy for DSTATCOM Using Reinforcement Learning Algorithm", IEEE ACCESS, July 30, 2018.

[34] Stadler, Michael, Cardoso, Gonçalo, Mashayekh, Salman, "Value streams in microgrids: A literature review". Applied Energy, 2015.

[35] Ashok Kumar L, Archana N. "Power Quality Improvement Of Grid Connected Wind Energy Systems Using Statcom-Battery Energy Storage System", ARPN Journal of Engineering and Applied Sciences, Vol. 10, No. 21, Nov. 2015.

[36] R. Mallick and S. Sinha, "Improvement of power quality in a DFIG based wind farm using optimized icosθ DSTATCOM", in 2015 IEEE Power, Communication and Information Technology Conference (PCITC). IEEE, 2015.

[37] K Hussain, J Praveen, "Power Quality Enhancement Using VSC Based DSTATCOM", International Journal of Engineering and Technology Volume 2 No. 1, January, 2012.

[38] Yuan-Chih Chang, Hao-Chin Chang and Chien-Yu Huang "Design and Implementation of the Battery Energy Storage System in DC Micro-Grid Systems", *energies*, 14 June 2018.