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Mitigation Of Voltage Fluctuations Due To 3P Oscillations Of Wind Farm Using Series Controller

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Abstract:

Rapid increase in demand for power, depletion of conventional energy sources and their adverse effects on environment is making power engineers to look for alternatives for power generation. Power generation through wind gained more popularity across the world due to technology advancements and low installation costs compared to solar and other sources of renewable energy. Grid integration of wind turbines has negative impact on grid operation due to random nature of wind, wind shear and tower shadow effects. Thus, the wind turbines are fluctuating power sources that influence power quality in distribution system. This paper presents a series controller for blocking these disturbances and maintaining the power quality within the acceptable limits defined by industry standards. The simulation results, carried out by using MATLAB/SIMULINK show the impact of these disturbances on the grid. The proposed series controller is found to be an effective tool in blocking disturbances at the point of common coupling and thereby maintaining the power quality.

Index Terms: Distributed Generation (DG), wind shear, tower shadow effect, 3p oscillations, wind generation, power quality, series controller.

1. Introduction

Distributed Generation (DG) by the use of renewable energy is gaining wide acceptance in these days due to socio-economic problems i.e., due to increased public concerns for adverse environmental factors and increased energy costs associated with the use of conventional energy sources. Among the renewable energy sources viz., solar, wind, biomass, geo-thermal, major portion of power generation through renewable energy sources is by wind turbines [1], [2] as they are environmental friendly, low installation cost compared to other sources of energy. Now-a-days, these sources are being interconnected to distribution system in small and large scale. The utilization of these sources indirectly reduces the line losses in the transmission as these sources are installed close to utilization point.

With the increase in wind power penetration into the grid, the power quality becomes a paramount issue for power engineers. Flicker is an important power quality issue for the operation of electrical equipment and may become a serious limitation to wind power especially in case of weak grids i.e., grids with low short circuit ratio. Many factors affect flicker emission of grid connected wind turbines during continuous operation such as wind characteristics and grid conditions [3]–[5]. The wind power fluctuations produced by grid connected variable speed wind turbines during continuous operation is mainly caused by fluctuations in aerodynamic torque due to wind speed variations, the wind shear and the tower shadow effects [4], [6] and [7]. The wind shear and tower shadow effects are referred to as 3p oscillations. These 3p oscillations result in output power to drop three times per revolution for a three bladed wind turbine [8]. This frequency is normally referred to as 3p. The 3p oscillation frequency component is transmitted to the output active power of the wind turbine, which will induce voltage fluctuation and flicker in the grid [8]. There are other factors that affect flicker emission of grid-connected wind turbines during continuous operation that include wind characteristics (e.g., mean wind speed, turbulence intensity), grid conditions (e.g., short circuit capacity, grid impedance angle) and types of wind turbines (e.g., fixed speed and variable speed). The flicker level is more [9], [10], [11]

- at higher wind speeds due to higher turbulence in the wind
- with lower short circuit level at the Point of Common Coupling (PCC) of the wind turbine
- if the difference between grid impedance angle and the wind turbine power factor angle approaches zero from 90^0
- in fixed speed wind turbines compared to variable speed wind turbines. For fixed speed wind turbines, flicker level increases around three times from lower to higher wind speeds [4]

Several methods have been proposed for mitigation of flicker origination from wind farms using Flexible AC Transmission Systems (FACTS) devices by controlling active power, reactive power and energy storage.

In one of the active power control methods, the flicker is eliminated by curtailing the active power being extracted from the wind turbine [12]. Another scheme of control known as Flicker Mitigation Controller (FMC) has been proposed [8]. This method dampens the flicker by varying dc-link voltage. FMC uses a vector control scheme for the Pulse Width Modulation (PWM) converter. The most commonly used technique for flicker mitigation is the reactive power compensation. For this Static Var Compensator (SVC) [13], Static Compensator (STATCOM) [14], [15], Unified Power Flow Controller [16] have been proposed. STATCOM proves to be superior to the SVC with respect to flicker mitigation [17], [18]. Another method known as Energy storage scheme of control [19] is also proposed and has not become popular because of its own drawbacks. STATCOMs serve two fold, they not only provide reactive power support but also with appropriately designed control strategy can eliminate flicker during continuous operation of fixed speed wind farms.

An effort is made here to overcome the integration barriers that help sustainable and clean DG technologies which contribute to the Power System in a way that enhances the overall grid performance. It is proved in this paper that the series controller can effectively be utilized to perform the following functions in the event of integration of wind power generators to power distribution system.

1) 100% evacuation of active power harvested from the wind
2) Mitigation of voltage fluctuations at PCC due to 3p oscillations resulting from wind farm
3) Unity power factor operation

In addition to the above objectives, the power quality is strictly maintained within the standards prescribed by IEEE-519 [20] and IEC-61000 standards.

2 System description and modeling:

2.1 System description:

The single line diagram of the power system under consideration with series controller is shown in Fig. 1. The network consists of 33KV, 50 Hz, grid supply point, feeding a 33KV distribution system. There are four load centers in the system L_1, L_2, L_3 and L_4. The four load centers comprise of Linear and Non-Linear loads. The Wind farm comprises of 3 wind turbines using squirrel cage induction generators each rated 3MW, 690V, 50Hz. Each generator is provided 170 KVAr fixed reactive power compensation through a bank of capacitors to give necessary reactive power support at the time of starting. The total wind farm of capacity 9MW is connected to the 33KV distribution system at the node Wind through a 690V/33KV transformer. In this study a mean wind speed of 9 m/s is considered. The Squirrel Cage Induction Generator model available in Matlab / Simulink SimPowerSystem libraries is used.

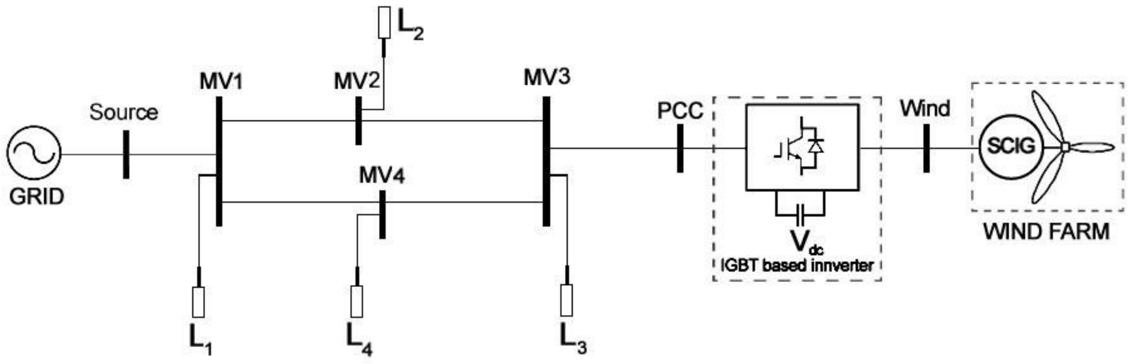

Fig. 1 One-Line diagram of distribution system with wind farm and Series controller

The power in the air flow is given by

$$P_{air} = \frac{1}{2} \cdot \rho \cdot \pi \cdot R^2 \cdot v^3 \tag{1}$$

The power transmitted to the wind turbine rotor, is always less [21], and gets reduced by the power coefficient, 'C_P'.

$$C_P = \frac{P_{wind\ turbine}}{P_{air}} \tag{2}$$

Therefore, the power that can be extracted from wind turbine is determined by the following expression:

$$P_{wind\ turbine} = \frac{1}{2} \cdot \rho \cdot \pi \cdot R^2 \cdot v^3 \cdot C_P \tag{3}$$

where 'ρ' is air density (approximately 1.25kgm^{-3}), 'R' is the radius of the swept area, 'v' is the wind speed and 'C_P' is the power coefficient. For the turbines used in the study, the values of R and C_P are 31.2 m and 0.45 respectively. The total power P_T from the wind farm is the arithmetic sum of the power generated by each turbine and is given by

$$P_T = \sum_{i=1}^{3} P_i \tag{4}$$

The wind speeds 'v' at different points of the swept area may substantially differ both in its mean and turbulence components. The speed variation at a rotating point can be separated into deterministic and stochastic components. The former is due to the spatial distribution of the mean speed whereas the latter is due to the turbulence. The factors that contribute to the deterministic component are primarily wind shear, tower shadow and the presence of other wind turbines and obstacles in the surroundings. On the other hand, the stochastic component is caused by the temporal and spatial distribution of turbulence.

In this paper, the disturbances due to wind shear and tower shadow which result in 3p oscillations is considered. The model developed for wind shear and tower shadow [6] is used here to study their impact on the power quality of distribution system to which the FSWT-SCIG is integrated. The wind speed (v) can be expressed as (5) the combination of these three factors shown in (6) to (8).

$$v = v_0 + v_{ws} + v_{ts} \tag{5}$$

$$v_0 = mV_H \tag{6}$$

$$v_{ws} = V_H \left[1 + \frac{\alpha(\alpha-1)}{8}\left(\frac{R}{H}\right)^2 + \frac{\alpha(\alpha-1)(\alpha-2)}{60}\left(\frac{R}{H}\right)^3 \cos 3\beta \right] \quad (7)$$

$$v_{ts} = \frac{mV_H}{3R^2} \sum_{b=1}^{3} \left[\frac{a^2}{\sin^2\beta_b} \ln\left(\frac{R^2 \sin^2\beta_b}{x^2} + 1 \right) - \frac{2a^2R^2}{R^2 \sin^2\beta_b + x^2} \right] \quad (8)$$

where $m = [1 + (\alpha(\alpha-1)R^2 / 8H^2)]$ is a coefficient of the wind turbine, V_H is the wind speed at hub height (in meters per second), α is the empirical wind shear exponent, H is the elevation of rotor hub (in meters), β is the azimuthal angle of each blade (in degrees), a is the tower radius (in meters) and x is the distance from the blade origin to the tower midline (in meters). The values chosen for these parameters for the study are given in appendix.

2.2 Compensation scheme:

Many methods have been proposed for mitigation of flicker. But the solutions proposed are for each turbine. The 3p oscillations resulting from one turbine appear as flicker in voltage at the PCC. Since flicker calculation requires long simulation time, the fluctuation in voltage is considered for the design of control scheme of series controller. A series controller is proposed in this paper for mitigation of fluctuations in voltage at PCC. The series controller employs a voltage source inverter (VSI) connected in series between the nodes PCC and wind as illustrated in Fig. 1. The VSI based series controller through suitable transformer eliminates voltage fluctuations whenever arises from wind farm. The series controller mainly consists of a converter and a control unit. The inverter is a three arm diode clamped IGBT based inverter with capacitor as dc storage element. The gate signals are generated with Pulse Width Modulation (PWM) scheme.

The Sine-Triangle Pulse Width Modulator (STPWM) control is used here. The switches of the inverter are controlled based on a comparison of a sinusoidal control and a triangular switching signal. A Phase Locked Loop (PLL) is used for extracting the frequency ‘f’ of the voltage at PCC (V_{PCC}). Reference voltage (V_{ref}) for each phase is obtained using the frequency ‘f’ in reference voltage manipulator.

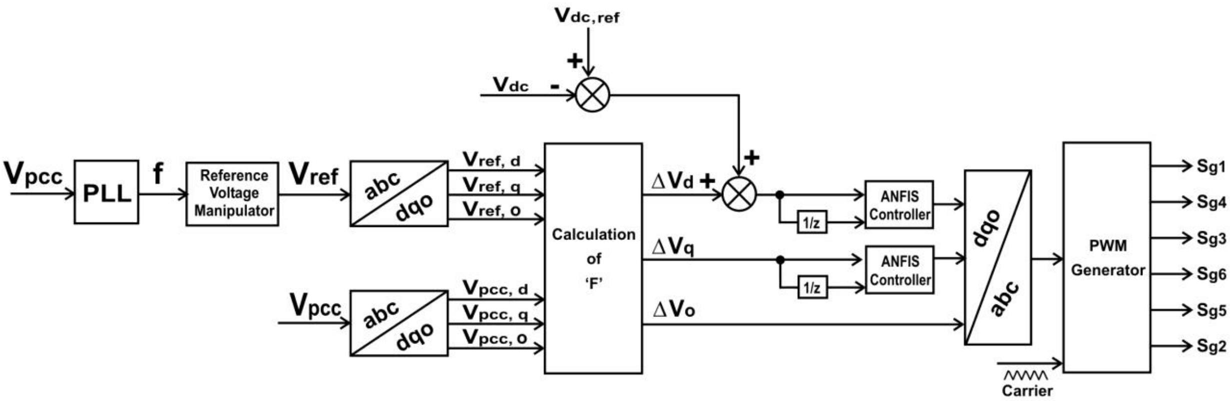

Fig. 2 Control scheme of Series controller

2.3 Detection of voltage fluctuation:

The algorithm proposed in [22], [23] is adopted here for quick detection of voltage fluctuation. It is schematically represented in Fig. 2. The voltage at PCC and the reference voltage is transformed to dqo reference frame. The difference between the reference voltage and the measured voltage at PCC in dqo reference frame is calculated as follows:

$$\Delta V_d = V_{ref,d} - V_{PCC,d} \quad (9)$$

$$\Delta V_q = V_{ref,q} - V_{PCC,q} \quad (10)$$

Further (5) & (6) are combined as

$$|\Delta V| = \sqrt{\Delta V_d^2 + \Delta V_q^2} \quad (11)$$

From (7), the fluctuation (F) in the voltage at PCC is expressed as

$$F = \frac{|\Delta V|}{\sqrt{V_{ref,d}^2 + V_{ref,q}^2}} \quad (12)$$

The deviation in voltages is processed by controller for generation of gate pulses. The controller can be PI, Fuzzy or ANFIS. Many reports claim that the fuzzy logic controller is superior compared to PI controller [24]-[27] as it can handle imprecise data, complex systems and can adopt to any changes in the systems. The PI controller is to be tuned properly for any change in system parameters. One main drawback of fuzzy controller is the lack of learning ability. The learning ability [28]-[30] and [22] of neural networks is combined with fuzzy and a new scheme of controller known as Adaptive Neuro-Fuzzy Inference System (ANFIS) [24] and [31] is considered in this work. An initial fuzzy inference system is taken from PI controller and is tuned with back propagation algorithm based on the collection of input-output data. For training the ANFIS controller, triangular membership function with seven input data pairs are used. The rule base used for the ANFIS controllers is illustrated in Table 1.

Table 1 Rule base for ANFIS controllers

		Input 2 (∫error (∫e))						
		NB	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
Input 1 (error (e))	**NB**	NB	NB	NB	NB	NM	NS	ZE
	NM	NB	NB	NB	NM	NS	ZE	PS
	NS	NB	NB	NM	NS	ZE	PS	PM
	ZE	NB	NM	NS	ZE	PS	PM	PB
	PS	NM	NS	ZE	PS	PM	PB	PB
	PM	NS	ZE	PS	PM	PB	PB	PB
	PB	ZE	PS	PM	PB	PB	PB	PB

The gate pulses are used for generation of three phase voltages by PWM converter. The output of the PWM converter is injected in series with the line as indicated in Fig. 2. The overall control logic of series controller works in such a way that the value of ‘ F ’ is zero.

3. Results & Discussion:

Simulations are carried out to study the operation of wind farm integrated to the power distribution system. The total simulation time considered is 3 sec. Simulations are carried out to show that the series controller mitigates the fluctuations in voltage at PCC. It is also shown that the disturbance originating from wind farm penetrates into the distribution system to with it is connected. A node MV2 to which a load, L_2, of 1.25MW is connected is chosen to show the influence of voltage fluctuation from wind farm and the effectiveness of series controller. The connected 3-phase load details at MV2 are Voltage: 33KV; Frequency: 50Hz; Active Power: 1.25MW; Inductive Reactive Power: 0.25MVar; Capacitive Reactive Power: 1KVar. The effects of wind shear and tower shadow on the power quality are dealt separately as detailed below:

Case 1 (with only tower shadow):

In this case, the simulation was conducted with the following chronology to analyze the effect of tower shadow:

- at t = 0.0 sec, the simulation starts with series controller not connected to the system
- at t = 1.0 sec, the voltage fluctuation originates from wind farm due to tower shadow only
- at t = 2.0 sec, the series controller is turned ON
- at t = 3.0 sec, the simulation stops

In the entire analysis the wind speed is considered to be $v = v_0$ in the range 0 < t < 1. To analyze the effect of tower shadow on the power quality, v_{ws} is set to zero in Eq. 5 in the time interval 2 < t < 5. The wind speed will be influenced only by tower shadow which is given by $v = v_0 + v_{ts}$. Fig. 3 shows the flicker (1 < t < 2) in voltage in phase-a at PCC due to tower shadow. The deviation in voltage is found to be 20%. This is objectionable as per the industry standards. The disturbance in voltage propagates into the distribution system and affects the operation of electrical equipment. This is evident from the Fig. 4. The real and reactive powers at the node MV2 is illustrated in Fig. 5 and Fig. 6 respectively.

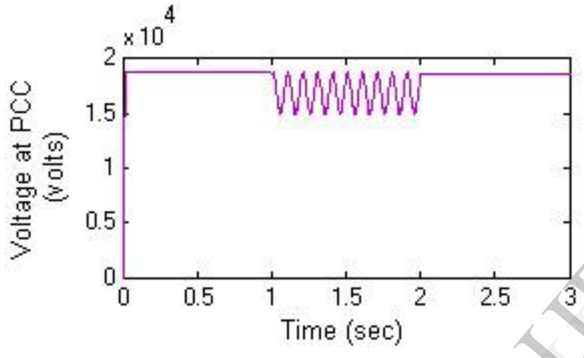

Fig. 3 Voltage in phase-a at PCC

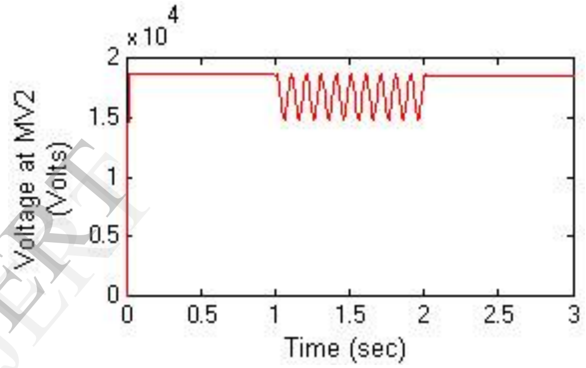

Fig. 4 Voltage in phase-a at node MV2

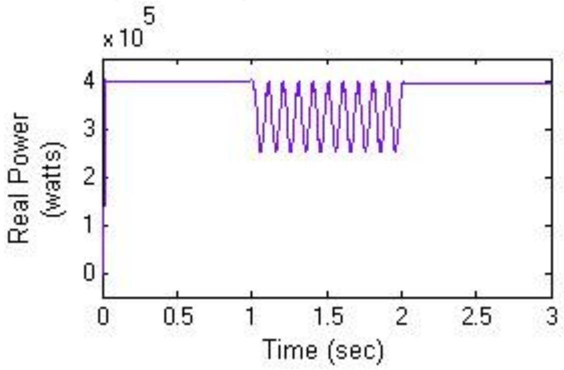

Fig. 5 Real power in phase-a at MV2

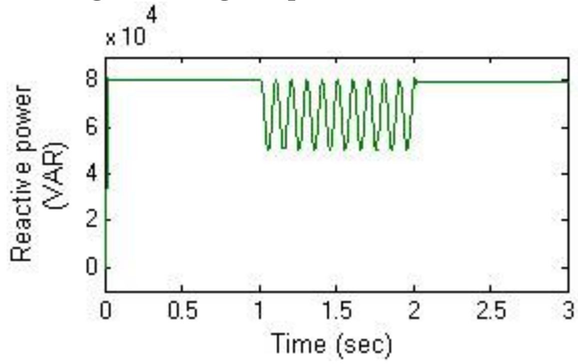

Fig. 6 Reactive power in phase-a at MV2

With the series controller brought into operation at t = 2 sec., the voltage fluctuation due to tower shadow effect is mitigated and the power quality is restored. This is evident from the illustrations Fig. 3 to Fig. 6.

Case 2 (with only wind shear):

In this case, the simulation was conducted with the following chronology to analyze the effect of wind shear:

- at t = 0.0 sec, the simulation starts with series controller not connected to the system
- at t = 1.0 sec, the voltage fluctuation originates from wind farm due to wind shear only
- at t = 2.0 sec, the series controller is turned ON
- at t = 3.0 sec, the simulation stops

Throughout the analysis the wind speed is considered to be $v = v_0$ in the range 0 < t < 1. To analyze the effect of wind shear on the power quality, v_{ts} is set to zero in Eq. 5 in the time interval 2 < t < 5. The wind speed will be influenced only wind shear which is given by $v = v_0 + v_{ws}$. Fig. 7 shows the flicker (1 < t < 2) in voltage in phase-a at PCC due to wind shear. The deviation in voltage is found to be 1.3%. The voltage disturbance propagates into the distribution system and effects the operation of electrical equipment. This can be noticed from the Fig. 8. The real and reactive powers at the node MV2 is illustrated in Fig. 9 and Fig. 10 respectively. The effect of disturbance in voltage due to wind shear is negligible compared to the flicker due to tower shadow.

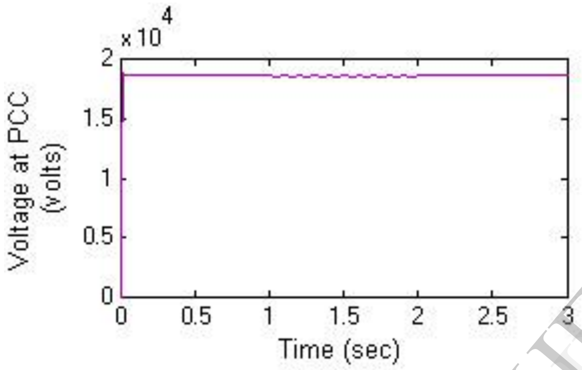

Fig. 7 Voltage in phase-a at PCC

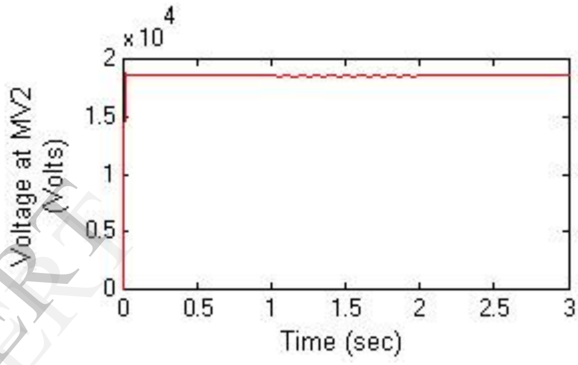

Fig. 8 Voltage in phase-a at node MV2

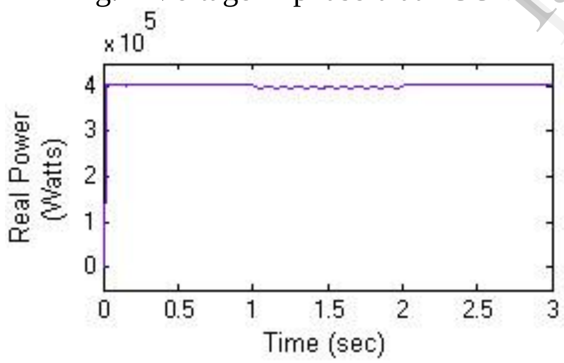

Fig. 9 Real power in phase-a at MV2

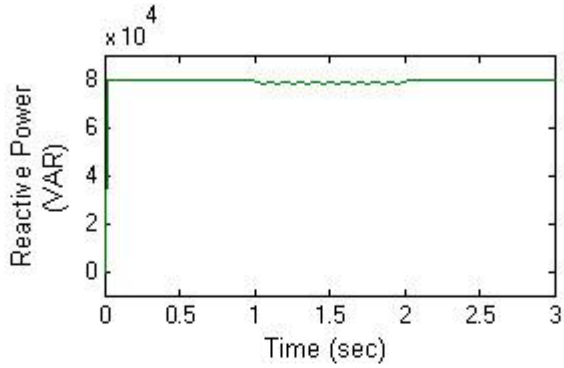

Fig. 10 Reactive power in phase-a at MV2

From the above illustrations, it is clear that the fluctuation in voltage is mainly due to tower shadow effect. The results are in good agreement with the results of [6]. Fluctuation in voltage due to tower shadow is an alarming condition that affects the quality of power. Power quality is a serious issue as the electronic equipment, induction motors etc., are very sensitive to flicker. Computers, adjustable-speed drives and process control equipment frequently trip as a consequence of a flicker in voltage.

The voltage pulsations arising from wind farm due to either wind shear or tower shadow at t > 1 sec. is mitigated with the series controller by turning it ON at t = 2 sec. From Fig. 3 to Fig. 10, it is evident that the series controller is able to maintain the power quality within the allowable limits of power quality standards.

Conclusion:

The effects of wind shear and tower shadow on power quality is analyzed separately. It is observed that the power quality is much affected due to tower shadow than wind shear. Series controller is suggested to overcome the power quality issues due to 3p oscillations. The importance of series controller is presented in this paper. The proposed controller is found extremely satisfactory for mitigation of voltage fluctuations originating from wind farm due to either wind shear or tower shadow. The disturbances in voltage are mitigated and the voltage is restored to its normal value. Thus, the proposed series controller is found more effective and efficient in mitigating voltage fluctuations while meeting the industry standards IEEE-519 and IEC-61000.

Appendix

Table – A

Parameters of SCIG coupled to Fixed-speed wind turbine

Parameter	Value
Rated power	3MW
Rated voltage	690V
Wind speed at hub height (V_H)	9 m/sec
Empirical wind shear component (α)	0.3
Wind turbine Rotor radius (R)	40 m
Elevation of rotor hub (H)	80 m
Distance from the blade origin to the tower midline (x)	5 m
Tower radius (a)	2 m

References:

[1] REN21: Renewables (2012) Global status Report.
[2] "Annual market update 2011", Global Wind Energy Council (GWEC), March, 2012.
[3] J. Slootweg and W. Kling, "The impact of large scale wind power generation on power system oscillations", *Elect. Pow. Sys. Res.*, vol. 67, no.1, pp. 9 – 20, 2003.
[4] A. Larsson, "Flicker emission of wind turbines during continuous operation", *IEEE Trans. Energy Convers.*, vol. 17, no.1, pp. 114 – 118, March, 2002.
[5] H. sharma, S. Islam, T. Pryor and C. V. Nayar, "Power quality issues in a wind turbine driven induction generator and diesel hybrid autonomous grid", *J. Electr. Electron. Eng.*, vol. 21, no. 1, pp. 19 – 25, 2001.
[6] Dale S.L. Dolan and Peter W. Lehn, "Simulation model of wind turbine 3p torque oscillations due to wind shear and tower shadow", *IEEE Trans. Energy Convers.*, vol. 21, no. 3, pp. 717 – 724, September, 2006.
[7] Xia Chen, Haishun Sun, Jinyu Wen, Wei-Jen Lee, Xufeng Yuan, Naihu Li, "Integrating Wind Farm to the grid using Hybrid Multiterminal HVDC Technology", *IEEE Trans. Ind. Appl.*, vol. 47, no. 2, March/April, 2011.
[8] Weihao Hu, Zhe Chen, Yue Wang and Zhaoan Wang, "Flicker mitigation by active power control of variable-speed wind turbines with full-scale back-to-back power converters", *IEEE Trans. Energy Convers.*, vol. 24, no. 3, September 2009.
[9] M. P. Papadopoulos, S. A. Papathanassiou, S. T. Tentzerakis and N. G. Boulaxis, "Investigation of the flicker emission by grid connected wind turbines", *Proc. 8th Int. conf. Harmonics Quality Power*, Athens, Greece, vol. 2, pp. 1152 -2 1157, 1998.
[10] P. D. Ladakakos, M. G. Ioannides, M. I. Koulouvari, "Assesment of wind turbines impact on the power quality of autonomous weak grids", *Proc. of the 8th Int. Conf. Harmonics and Quality of power*, vol. 2, pp. 900 – 905, October, 1998.

[11] H. amaris, C. Vilar, J. Usaola, J. L. Rodriguez, "Frequency domain analysis of flicker produced by wind energy conversion systems", *Proc. of the 8th Int. Conf. Harmonics and Quality of power*, vol. 2, pp. 1162 – 1167, October, 1998.

[12] M. Triggianese, J. Morren, D. Haan and P. Marinao, "Improved and extended DG capability in voltage regulation by reactive and active power", *Proc. Int. Conf. Power eng., Energy Electr. Drives*, Setubal, Portugal, apr. 2007, pp. 583 – 588.

[13] Y. Kubota, T. Genji, K. Miyazato, N. Hayashi, H. Tokuda, Y. Fukuyama, "Verification of cooperative control method for voltage control equipment on distribution network simulator considering interconnection of wind power generators", *Proc. of Trans. and Dist. Conf. and exhibition 2002: Asia Pacific*, vol. 2, pp. 1151 – 1156, October, 2002.

[14] Z. Zhang, N. R. Fahmi, W. T. Norris, "Flicker analysis and methods for electric arc furnace flicker (EAF) mitigation (a survey)", Proc. of 2001 *IEEE Proto Power Tech conf.*, vol. 1, pp. 6/1 – 6/6, September, 2001.

[15] T. Larsson, C. Poumarede, "STATCOM, an efficient means for flicker mitigation", *Proc. of the IEE Power Engineering society 1999 Winter meeting*, pp. 1208 – 1213, Jan./Feb. 1999.

[16] A. Papantoniou, A. Coonick, "Simulation of FACTS for wind farm applications", *Proc. of the IEE colloquium on Power Electronics for Renewable energy*, pp. 8/1 – 8/5, June, 1997.

[17] Z. Saad-Saoud, M. L. Lisoba, J. B. Ekanayake, N. Jenkins, G. Strbac, "Application of STATCOMs to wind farms", *IEE Proc. Generation Transmission Distribution*, vol. 145, no. 5, pp. 511 – 516, September, 1998.

[18] J. E. Hill, "A practical example of the use of distribution static compensator (D-STATCOM) to reduce voltage fluctuation", *Proc. of the IEE colloquium on Power Electronics for Renewable Energy*, pp. 7/1 – 7/5, June, 1997.

[19] D. S. Docopoulos , C. S. Dimoulias, I. M. Manousaridis, A. X. Patralexis, "Improvement of power quality in a grid with wind turbines using inductive storage", *Wind Engineering*, vol. 23, no. 4, pp. 215 – 224, 1999.

[20] "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems", ANSI/IEEE Std. 519 – 1992, New York, 1993.

[21] T. Burton, D. Sharpe, N. Jenkins and E. Bossanyi, Wind Energy Hand Book, New York: Wiely, 2001.

[22] O. C. Montero-Hernaandez and P. N. Enjeti, "A fast detection algorithm suitable for mitigation of numerous power quality disturbances", *conf. Rec. IEEE-IAS Annu. meeting*, 2001, pp. 2661-2666.

[23] Koen J. P. Macken, Math H. J. Bollen and Ronnie J. M. Belmans, "Mitigation of Voltage dips through distributed generation systems", *IEEE Trans. on Ind. Appl.*, vol. 40, no. 6, November/December, 2004.

[24] A. Hamadi, K. Al-Haddad, S. Rahmani and H. Kanaan, "Comparision of Fuzzy logic and Proportional Integral controller of voltage source active filter compensating current harmonics and power factor", *IEEE Int. Conf. on Ind. Tech.*, pp. 645 – 650, 2004.

[25] Nitin Gupta, Singh S. P. and Dubey S. P., "Fuzzy logic controlled shunt active power filter for reactive power compensation and harmonic elimination", *IEEE Int. Conference on Computer and Communication Technology (ICCCT)*, pp. 82 – 87, September, 2011.

[26] Singh G. K., Singh A. K., Mitra R, "A simple fuzzy logic based robust active power filter for harmonics minimization under random load variation", *Elec. Power Sys. Res.*, vol. 77, pp. 1101 – 1111, 2007.

[27] Ying H, "Fuzzy control and modeling: Analytical foundations and Applications, IEEE Press, 2000.

[28] Vazquez J.R. and Salmeron P, "Active power filter control using neural network technologies", *IEE Proc. Electr. Power Appl.*, vol. 150, no. 2, pp. 139 – 145, March, 2003.

[29] Rukonuzzaman M and Nakaoka M, "An advanced active power filter with adaptive neural network based harmonic detection scheme", *IEEE Conf. Power Electronics Specialists Conference (PESC)*, Vol. 3, pp. 1602 – 1607, 2001.

[30] Nitin Gupta, Singh S. P. and Dubey S. P., “Neural network based shunt active filter for harmonic and reactive power compensation under non-ideal mains voltage”, *IEEE Int. Conf. Industrial electronics and applications (ICIEA)*, pp. 370 – 375, June, 2010.

[31] Jhy-Shing Roger Jang, “ANFIS: Adaptive-Network-Based Fuzzy Inference System”, *IEEE Trans. on Systems, Man and Cybernetics*, Vol. 23, No. 3, pp. 665-685, May/June, 1993.

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