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Experimental Resultsofa Wind Energy Conversion Systemwith STATCOM Using Fuzzy Logic Controller

S. A. Gawish, SM Sharaf, M. S. El-Harony
Department of Electrical Power and Machines Engineering, Faculty of Engineering of Helwan
University of Helwan, Cairo, Egypt
*Corresponding author, e-mail: eei@journal.uad.ac.id

Abstract

This paper describes a complete implementation of the experimental voltage regulation of a wind energy conversion system using STATCOM. Firstly conventional control technique is used which is proportional plus integral controller. The control technique is performed using a PC computer through a suitable interfacing and opt-isolating facilities. Secondly fuzzy logic controller is facilitated in this scheme to improve the performance of the experimental setup. Several efforts are done to choose the suitable gains of the fuzzy controller to achieve superior performance of the wind system. Experimental results of the system show the effectiveness of the proposed technique in regulating the output voltage. Thanks to the operation of the STATCOM in controlling the reactive power of the system to fix the output voltage at the desired value regardless of the wind speed.

Keywords*: wind system, STATCOM, Voltage stabilization, PI controller, fuzzy logic controller*

1. Introduction

Moreover, wind power is expected to be economically attractive when the wind speed of the proposed site is considerable for electrical generation and electric energy is not easily available from the grid. Wind system with STATCOM is very reliable because the STATCOM acts as a cushion to take care of variation in wind speed and would always maintain an average voltage equal to the set point. However, in addition to the unsteady nature of wind, another serious problem faced by the isolated power generation is the frequent change in load demands. This may cause large and severe oscillation of power.

Several tests are made to validate the system response at different operating conditions. Different choices of the scaling factors of the fuzzy logic controller have been assumed toobtainthe best response of the system. The test results are recorded and plottedfor a wide range in wind speed. Output power, inverter current, inverter voltage, and STATCOM control voltage (Vc) are recorded. In each test change in wind speed, several combination of scaling factors are asummed. Which system is regulated at different wind speed [1, 2]. Nevertheless, under the sudden change of load demands and random wind power input, the pitch controller of the wind side able to effectively control the system frequency due to theirs slow response. FACTS devices can be a solution to these problems [3]. They are able to provide rapid active and reactive power compensations to power systems, and therefore can be used to provide voltage support and power flow control, increase transient stability and improve power oscillation damping. Suitably located FACTS devices allow more efficient utilization of existing transmission networks. Among the FACTS family, the shunt FACTS devices such as the STATCOM has been widely used to provide smooth and rapid steady state and transient voltage control at points in the network. In this paper, a STATCOM is added to the power network to provide dynamic voltage control for the wind system, dynamic power flow control for the transmission lines, relieve transmission congestion and improve power oscillation damping.

Following sections deals with the experimental tests of the wind system equipped with STATCOM. Proportional plus integral controller schemes are used to improve the voltage regulation and to minimize the voltage fluctuation during variation in wind speed. Several experimental tests are performed to adjust the proportional plus integral gains at optimal operation of the practical system. Each test describe the voltage adjust by injection voltage by STATCOM. In addition, the controlling voltage of the STATCOM is recorded.

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Fuzzy logic controller (FLC) [4, 5], is an evolutionary computation technique that has been applied to other voltage engineering problems, giving better results than classical techniques and with less computational effort. In this paper the gains of the controllers with STATCOM have been optimized and optimum transient by trial and error it using to determine the optimal parameters of the PI controller in STATCOM such as PI controller in AC voltage regulator, DC voltage regulator.

2. Experimental System Implementation

Figure 1 shows a complete block diagram of the experimental system, which consists of the DC motor emulation as a wind turbine, three phase synchronous generator, single phase converter, firing circuit , electrical load and grid, speed and current sensors, over-head transmission line, interface circuit and PC computer.

A separately excited DC motor is used to emulate the characteristics of the wind turbine. The armature current of the motor is controlled so that it can have the different active powers at different wind speeds while the rotor speed is constant due to the grid connection of the synchronous generator. Figure 2 shows the functional block diagram of the laboratory simulator of the wind turbine using a DC motor with current control technique.

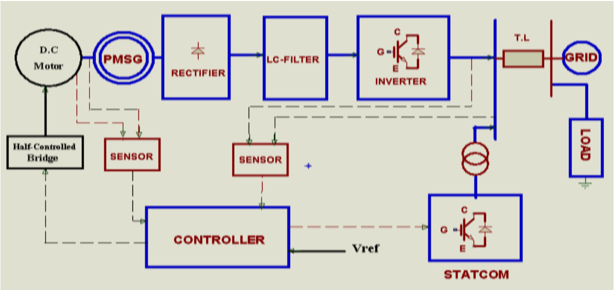


Figure 1. Block diagram of the experimental system with STATCOM

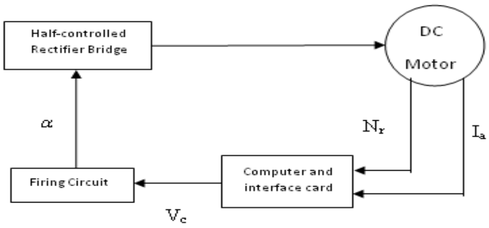


Figure 2. Block diagram of the DC motor emulation

The input signals are the DC machine armature current that used to calculate the electrical power of the DC machine; the second input signal is the rotor speed that used to calculate the electric frequency of the generated voltage. The output signals are the firing voltage that controls the firing angle of the single phase converter that control the current of the DC machine in current control loop to enable the machine to be behaves as a real wind turbine. The output signals are the firing voltage of D.C motor. The experimental model is simple and more economical. Figures 3-5 show the experimental circuits.

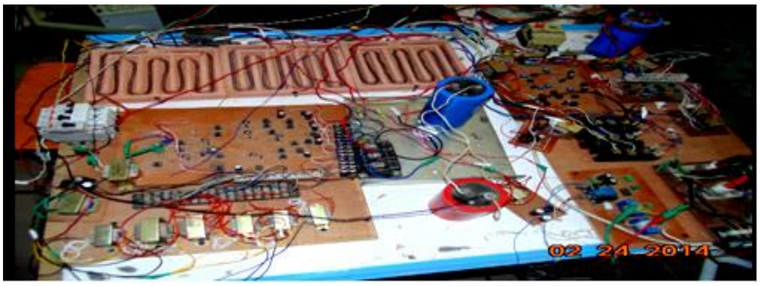
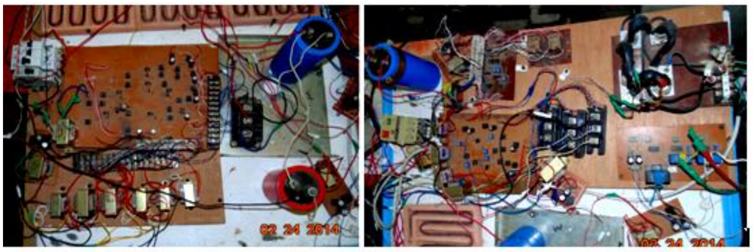


Figure 3. Photograph of the experimental control circuit



(a) (b)

Figure 4. Photograph of (a) STATCOM (b) inverter

(a) (b)

Figure 5. Photograph of (a) motor generator set (b) DC Bridge

3. Wind Turbine Performance without STATCOM

In the following sections the behaviour of the wind energy system will be studied when the wind system connected to infinite bus of constant voltage and frequency (direct connected to the main grid), before connection to the grid, the synchronization must be done, the generator was soft started and its output voltage and frequency are adjusted from their fields at rated values of 380V, and 50Hz. Since the proposed wind energy system is directly connected to the grid the following different cases are studied as shown in the following sections.

In this section, the wind energy is operated in open loop mode to evaluate the performance of wind turbine. To demonstrate the response of the system, the wind speed will be fixed at particular value for certain time and after the system reaches its steady state, the system will be subjected to step change in the wind speed.

Experimental results depicting the variation of the various variables for step change in wind speed are shown in Figures 6-9.

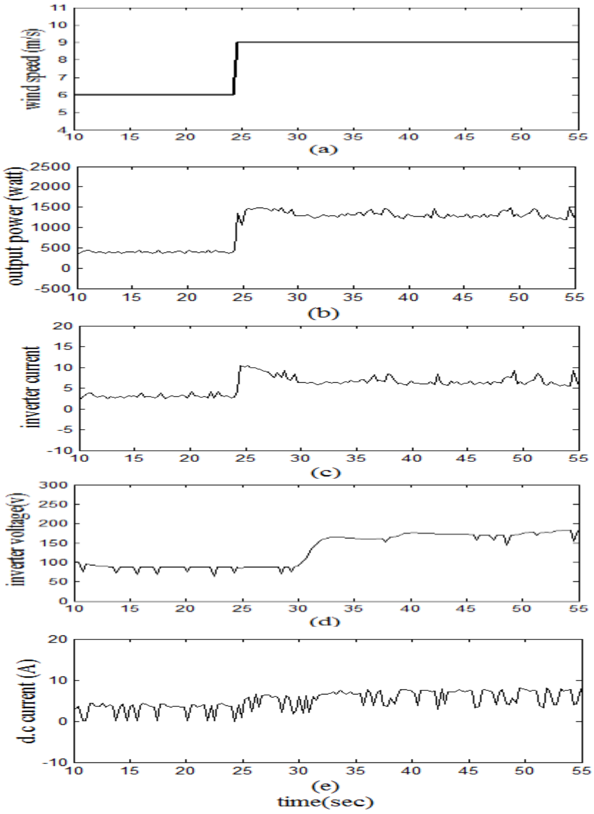


Figure 6. Wind turbine performance with inverter at step up in wind speed

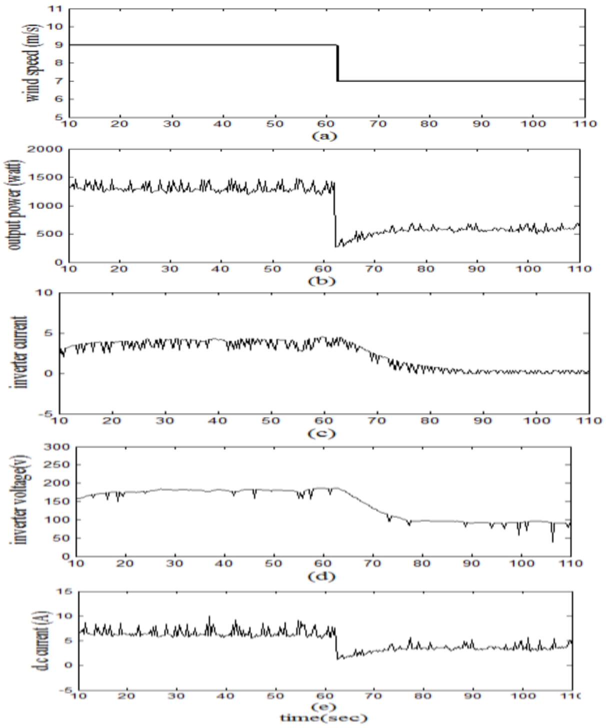


Figure 7. Wind turbine performance with inverter at step down in wind speed

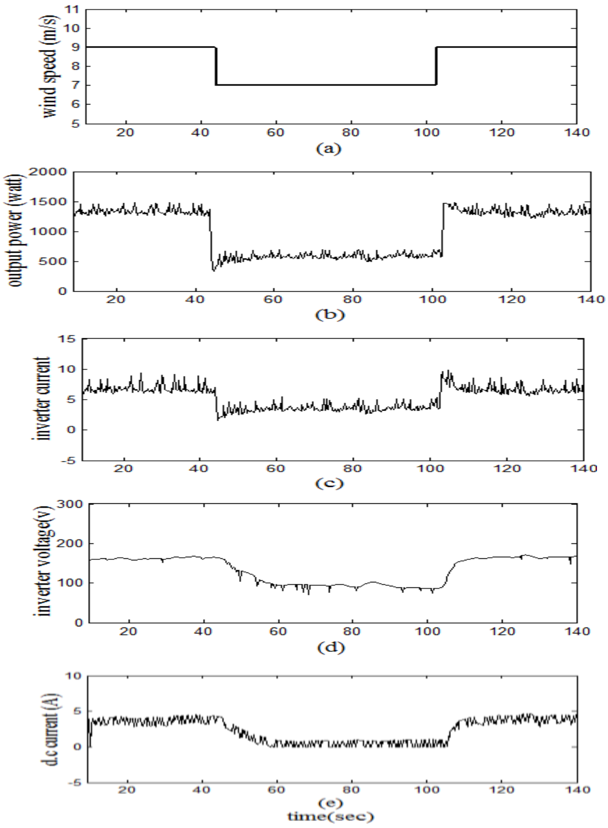


Figure 8. Wind turbine performance with inverter at step up-down-up in wind speed

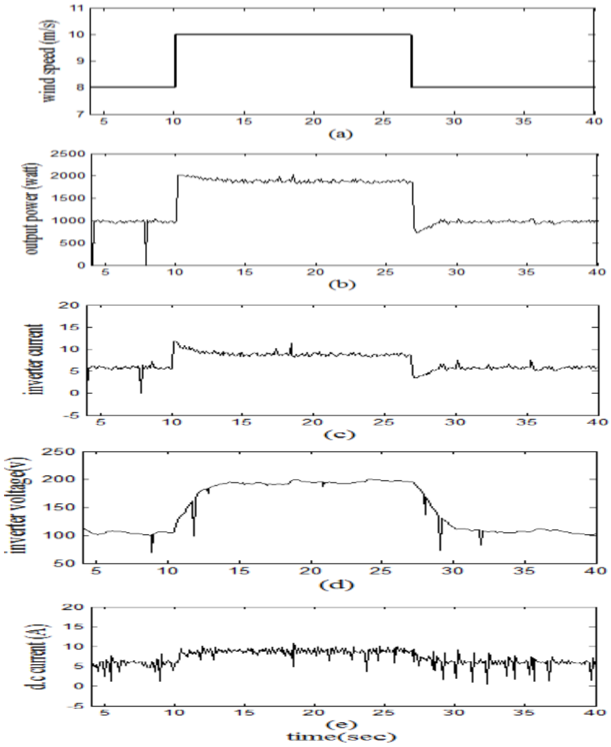


Figure 9. Wind turbine performance with inverter at step down-up-down in wind speed

From those figures the output power and inverter voltages following the changes in wind speed. Above sections deals with the experimental tests of the wind speed, if it increases, the output power, the inverter current, the inverter voltage, and D.C current are increase. If the wind speed decreases the output power, the inverter current, the inverter voltage, and D.C current are decrease.

4. Wind Turbine Performance with STATCOM and Connected to Grid

A STATCOM is used to supply the A.C voltage from a DC capacitor. This can be achieved by using a reliable firing circuit.

4.1. Voltage Regulation of a Wind Energy System with STATCOM using PI Controller

In open loop experimental results has been shown that the electrical power generated and voltage is fluctuated according to the operating wind speed. To regulate the output voltage regardless of the wind speed, STATCOM is used to control the reactive power of the system.

A proposed controller called proportional-integral controller will be designed on a PC computer using MATLAB software package and LAPVIEW software. Figures 10-13 show the performance of the wind energy system at suddenly step change in wind speed.

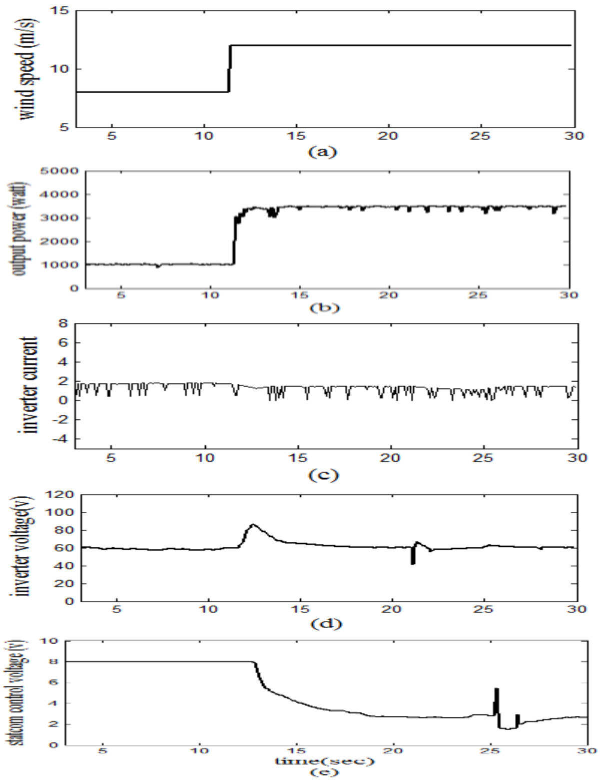


Figure 10. Experimental voltage regulation of wind system at step up in wind speed using PI controller

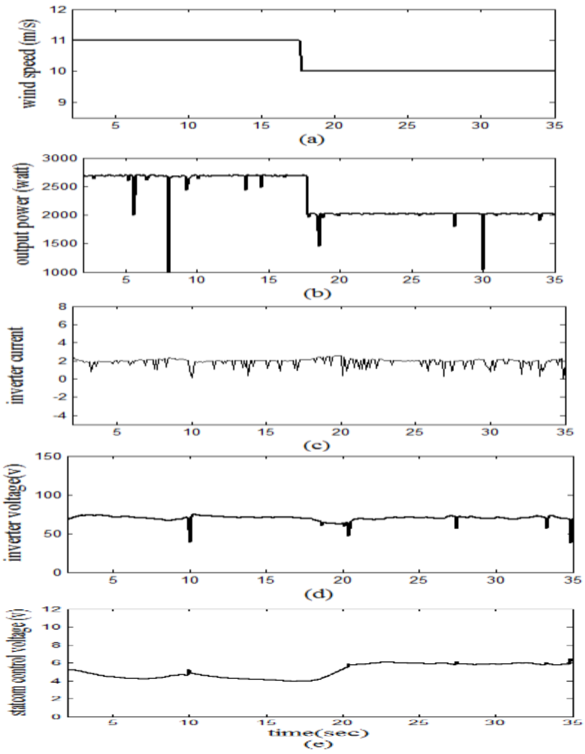


Figure 11. Experimental voltage regulation of wind system at step down in wind speed using PI controller

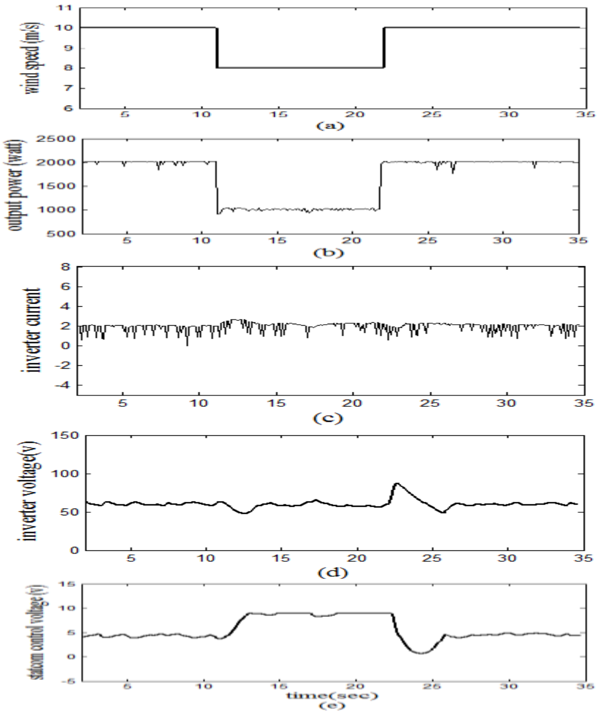


Figure 12. Experimental voltage regulation of wind system at step up-down-up in wind speed using PI controller

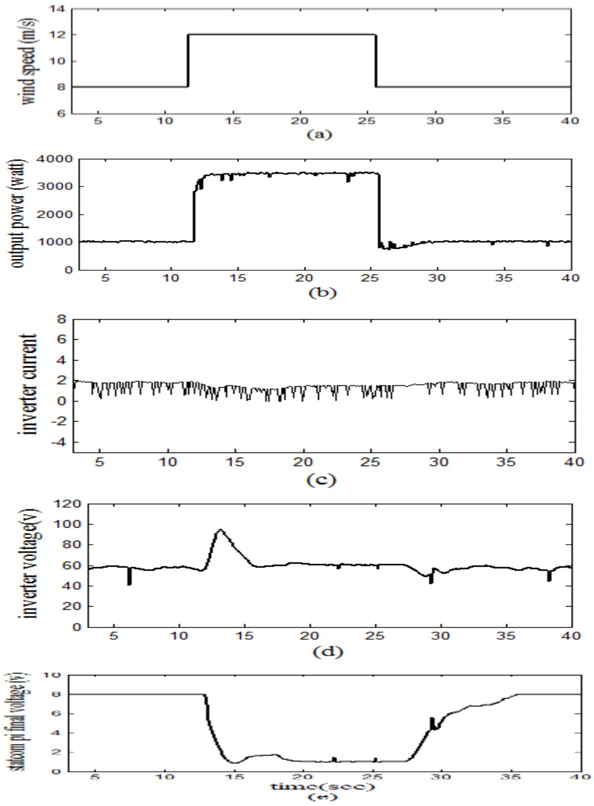


Figure 13. Experimental voltage regulation of wind system at step down-up-down in wind speed using PI controller

From those figures the inverter voltages is fixed at any changes in wind speed due to the use of STATCOM.

5. Voltage Regulation of a Wind Energy System with STATCOM using Fuzzy Logic Controller

Several tests are made to validate the system response at different operating conditions. Different choices of the scaling factors of the fuzzy logic controller have been assumed toobtainthe best response of the system. The test results are recorded and plotted in the following figures for a wide range in wind speed. Output power, inverter current, inverter voltage, and STATCOM control voltage (Vc) are recorded. In each test change in wind speed, several combination of scaling factors are asummed. Figures 14-20 show the regulating system at different wind speeds.

From those figures the inverter voltages is fixed at any changes in wind speed due to the use of STATCOM. The voltage response is better than of using PI controller, where the response is fast and less steady state error in case of fuzzy logic controller.

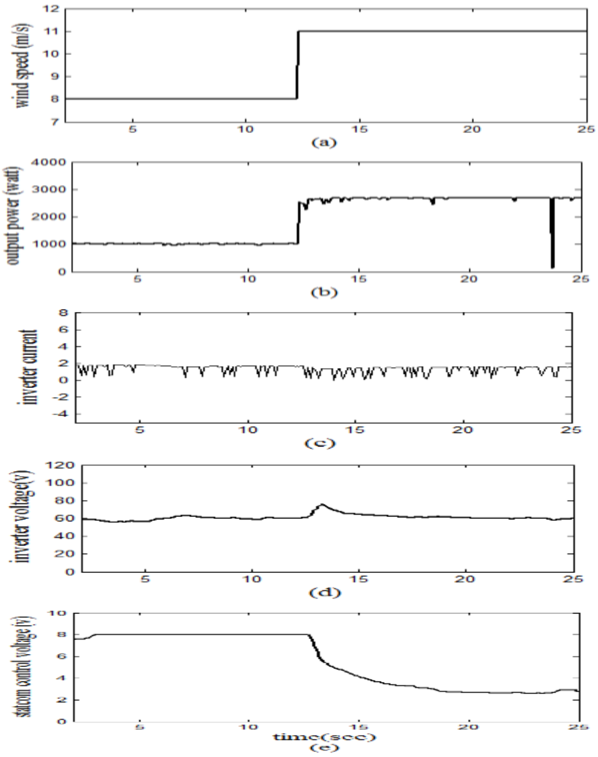


Figure 14. Experimental voltage regulation of wind system at step up in wind using fuzzy logic controller

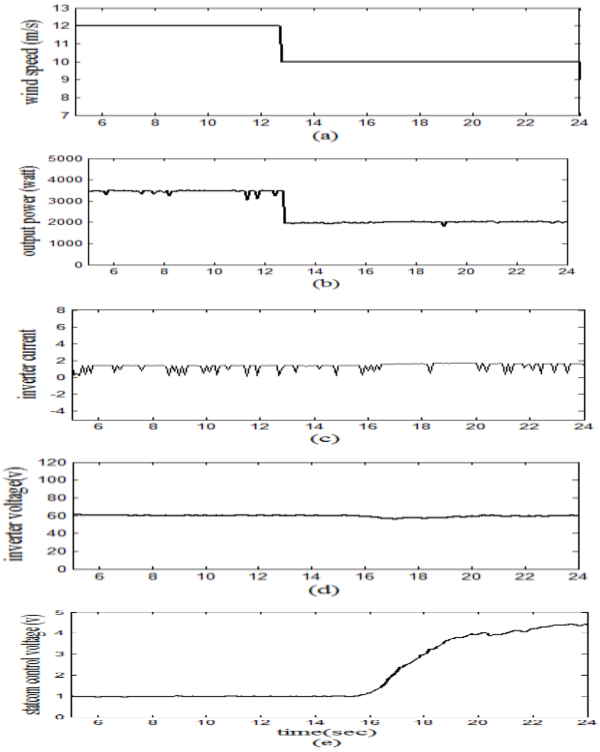


Figure 15. Experimental voltage regulation of wind system at step down in wind using fuzzy logic controller

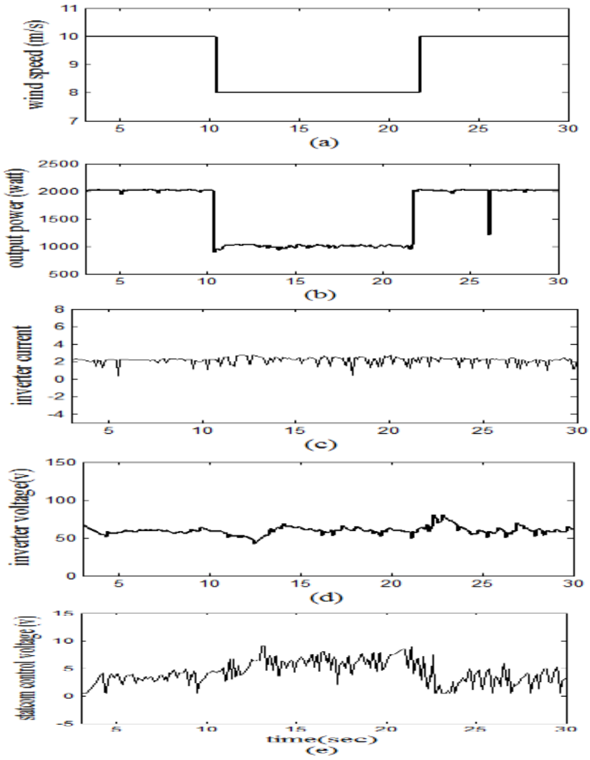


Figure 16. Experimental voltage regulation of wind system at step up and down in wind using fuzzy logic controller

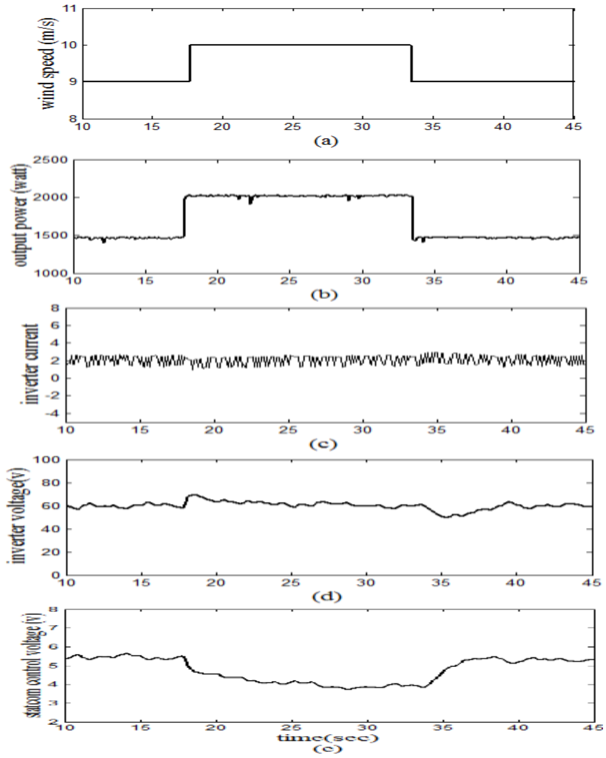


Figure 17. Experimental voltage regulation of wind system at step down and up and down (small step in wind speed) in wind using fuzzy logic controller

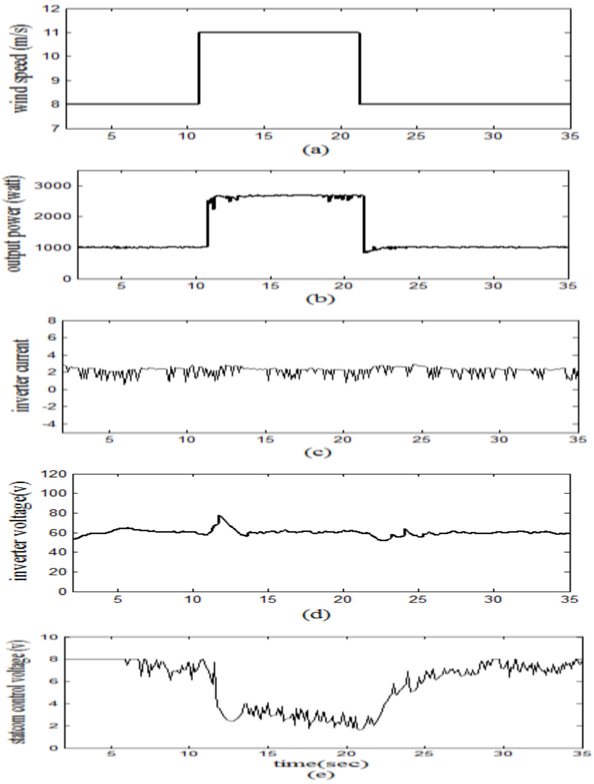


Figure 18. Experimental voltage regulation of wind system at step down and up and down (high step in wind speed) in wind using fuzzy logic controller

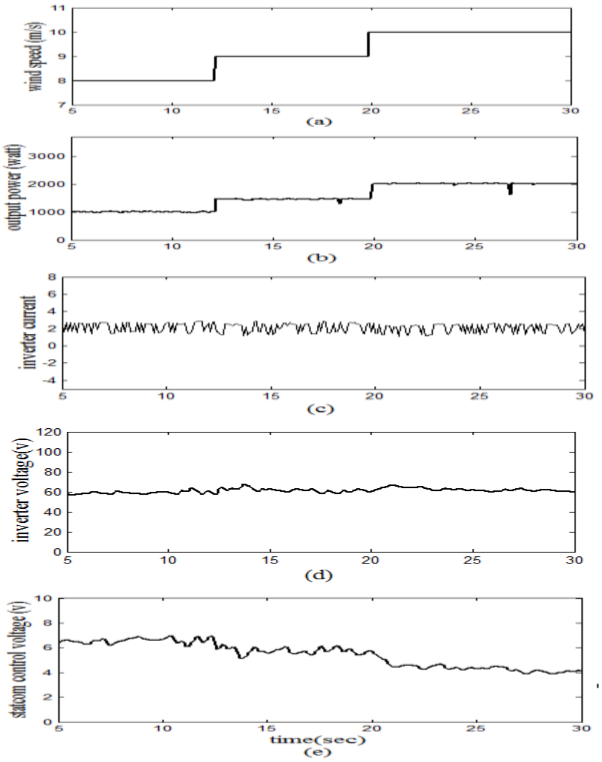


Figure 19. Experimental voltage regulation of wind system at step up in wind speed in steps using fuzzy logic controller

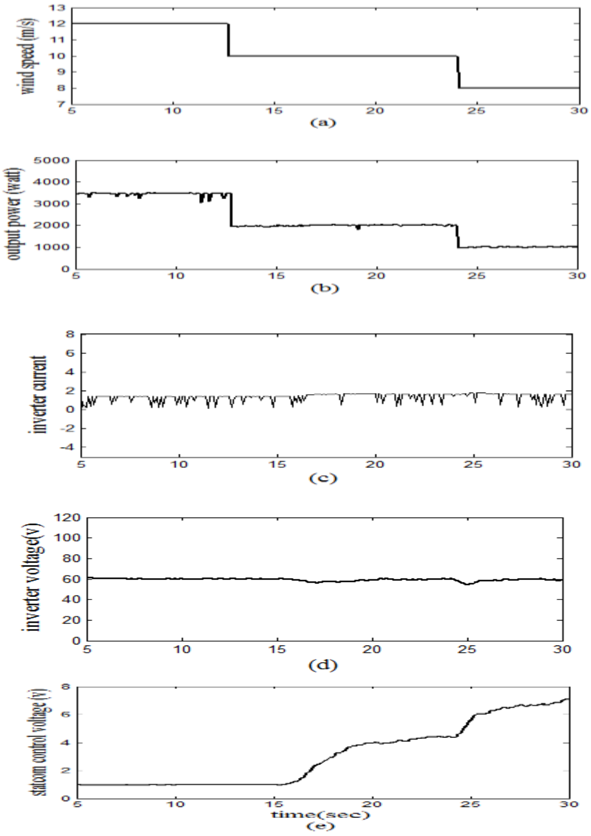


Figure 20. Experimental voltage regulation of wind system at step down in wind speed in steps using fuzzy logic controller

6. Conclusion

This paper concerned with solution of the voltage problems of the wind energy system. Several techniques are proposed to regulate the output voltage of the wind system. Digital controller is developed such as proportional plus integral, and fuzzy logic to achieve the best performance of the STATCOM. Wide range of operating conditions of wind speed was considered in this paper to achieve the most suitable controlling technique.

From the results shown in this paper, it can be concluded that the STATCOM is an effective controller in controlling the wind energy system voltage during normal conditions. The grid voltage at point of common coupling (PCC) is still constant at any step change in wind speed due to the effect of adding STATCOM. The STATCOM delivering or absorbing reactive power depends on the voltage level.

All results and comparison with them illustrates the voltage regulation of inverter voltage in case of using a fuzzy controller is better than in case using a PI controller, where the response is fast with small steady-state error. With STATCOM controller the voltage of the inverter was independent of the winds speed. That means, the STATCOM was fully regulated to achieve a constant inverter voltage independent the wind speed variations.

References

[1] Energinet.dk: ‘Wind turbines connected to grids with voltages above 100 kV – Technical regulations for the properties and the control of wind turbines’, Energinet.dk, Transmission System Operator of Denmark for Natural Gas and Electricity, Technical Regulations TF 3.2.5, Available: www.energinet.dk. 2004: 1-30.

[2] C Schauder, M Gernhardt, E Stacey, T Lemak, L Gyugyi, WT Cease, A Edris. "Development of a ±100 MVAr static condenser for voltage control of transmission systems". *IEEE Transactions on Power Delivery*. 1995; 10(3): 1486 – 1496.

[3] SH Hosseini, R Rahnavard, Y Ebrahimi. "Reactive Power Compensation in Distribution Networks with STATCOM by Fuzzy Logic Theory Application". *Power Electronics and Motion Control Conference*. 2006; 2: 1-5.

[4] Jang JSR. "ABFIS: Fuzzy Inference System". *IEEE Transactions on Systems, Man and Cybernetics*. 1993; 23(3): 665-685.

[5] MAM Prats, JM Carrasco, E Galvan, JA Sanchez, LG Franquelo, C Batista. "Improving transition between power optimization and power limitation ofvariable speed, variable pitch wind turbines using Fuzzy control techniques". *IECON* - Proc. 2000; 3(1): 1497-1502.

[6] Ackermann T. "*Wind Power in Power Systems*". John Wiley & Sons. 2005.

[7] Akhmatov V. Analysis of dynamic behavior of electric power systems with large amount of wind power. PhD thesis. 2003. Ørsted DTU.

[8] JD Hanson, C Horwill, J Loughran, RD Monkhouse. "The application of a relocatable STATCOM-based SVC on the UK National Grid System". *Transmission and Distribution Conference and Exhibition, IEEE/PES*. 2002; 2: 1202-1207.

[9] Petitclair P, Bacha S, Ferrieux JP. "*Optimized linearization via feedback control law for a STATCOM*". France. 1997: 880 – 885.