Simultaneous Implementation of STATCOM and SVC to Control the Reactive Power of Hybrid Wind Turbines

Abbas Khorshidi

Electrical Engineering Department of Abadan Oil Refining Co.Iran

Corresponding author: Abbas Khorshidi

ABSTRACT: The use of the isolated hybrid power systems is being popular due to thecontinuous increasing gap between demand and supply of conventional energy sources and intermittent nature of non- conventional energy sources. Normally, the non-conventional energy source such as wind have induction generator to generate electricity but induction generators require reactive power for its operation and this demand is continuously changing by the variation of load and wind power. The synchronous generator used in hybrid system for generating power through diesel system is supplying reactive power to the system partially; therefore, another source of reactive power is required to fulfill this demand. In this paper, the static VAR compensator (SVC) and static synchronous compensator (STATCOM) using a proportional- integral controller (PI) are used as reactive power compensator. The dynamic performance of SVC and STATCOM are investigated for wind-diesel and wind -diesel-microhydro power systems ate constant slip operation of induction generators. The results show that the STATCOM is a better option than that of SVC for reactive power control of the hybrid system.

Keywords: hybrid wind power system; energy sources;renewable energy sources; synchronous generator; SVC and STATCOM.

INTRODUCTION

There has been a continuous enhancement of power generation from renewable energysources in recent years. The reasons for renewable energy sources getting more and more popular are that they are clean sources of energy, able to replenished quickly, sustainable, and eco-friendly. The only drawback is that they are intermittent in nature. To enhance the capacity and reliability of the power supply of local grids, the non-conventional energy sources like wind, mini/micro hydro, etc. are integrated with diesel system. This combination of conventional and renewable sources is called as isolated hybrid power system [1]-[2]. Normally, synchronous generators and induction generators are chosen with diesel generators and wind turbines respectively [3]. Reduction in unit cost, ruggedness, brushless (in squirrel cage construction), absence of separate DC source for excitation, easy maintenance, self protection against severe overloads and short circuits etc, are the main advantages [4]-[5]. Induction generators offer many advantages over synchronous generators in an isolated hybrid power system but require reactive power for their operation. Due to this mismatch between generation and consumption of reactive power, more voltage fluctuations at generator terminal occur in an isolated system which reduces the stability and quality of the supply. The problem becomes more complicated in hybrid system having both induction and synchronous generator. Many papers have appeared in the literature, which suggest different methods using a bank of fixed capacitors for providing the reactive power under steady state conditions [7]-[8]. As induction generator reactive power demand varies, the fixed capacitors are unable to provide adequate amount of reactive power support to isolated power system under varying input wind power and load conditions [6]. Various Flexible AC transmission system (FACTS) devices areavailable those can supply fast and continuous reactive power [9-11]. Therefore, for standalone applications, and effective capacitive VAR controller has become central to the success of the induction generator system. Switched Capacitors, SVC, and STATCOM can provide the reactive power. A switched capacitor scheme is cheaper, but it regulates the

terminal voltage in discrete steps. Large values of capacitors and reactors are required in SVC scheme [13]. STATCOM [14] - [16] employs a voltage source inverter (VSC) that internally generates inductive/capacitive reactive power which has the advantages over the SVC scheme [17].

This paper presents dynamic stability study of wind-diesel and wind-diesel-microhydro systems with realistic load power disturbance. The realistic comprises 1% step increase plus band limited white noise signal. SVC and STATCOM are used for control of reactive power in the system. The gains of the controllers with SVC and STATCOM have been optimized and optimum transient responses are shown.

Dynamic model of the System

The wind-diesel power system in general comprises induction generator, synchronous generator, electrical loads and reactive power compensator (SVC or STATCOM) and a control mechanism. A single line diagram of the system is shown in Figure 1. The active power demand of the load is fulfilled by the synchronous generator and the induction generator. The reactive

Power required for the operation of induction generator and load is provided by synchronous generator and SVC/STATCOM and equations for the system shown in Figureure1 is given by,

$$P_{IG} \quad {}^{P}S\,G \square\,P_L \tag{1}$$

$$Q\,S$$
$$G \;+\; {}^{Q}com = Q_L + Q_{IG} \tag{2}$$

Due to disturbance in load reactive power Q_L, the system voltage may change which results incremental change in reactive power of other components. The net reactive power surplus is $Q_{S\,G} + Q_{co\,m} - Q_L - Q_{IG}$ and it will change the system voltage which will

govern by the following transfer function equation.

$$V(s) = \underline{K_v} \quad \square \; Q_{SG}(s) + \; Q_{com}(s) - \; Q_L(s) - \; Q_{IG}(s)\square \tag{3}$$
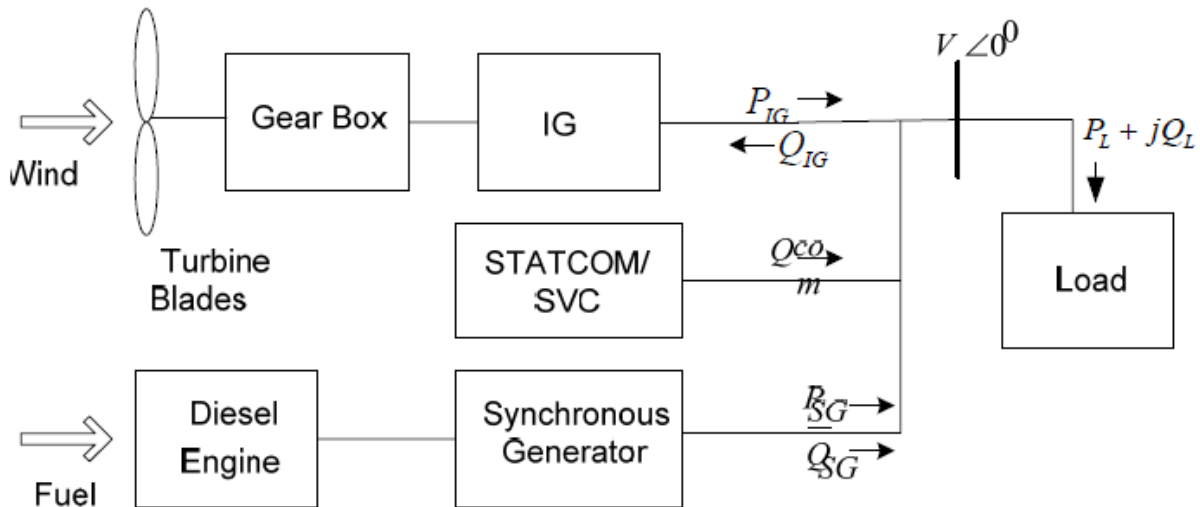

Figure 1. Single line diagram of awind diesel power system

The incremental change in reactive power of the synchronous generator Q_{SG} in equation

(3)   depends
upon E_q' and V . The corresponding transfer equation is given by,

$$\qquad \qquad ' \; (\quad s \quad) \tag{4}$$
$$Q_{SG}(s) = K_1 \quad E_q' + K_2 \quad V(s)$$

The transfer function equation for the state variable $E_q'(s)$ is obtained from the flux

linkage equation of the synchronous generator along with the excitation system (IEEE type-I) as given in reference [11]. The induction generator requires reactive power under constant slip

condition and the incremental change in reactive power of induction generator, Q_{IG} depends

upon V. The corresponding transfer function equation is given by,

$$Q_{IG}(s) = K_3 \ V(s) \tag{5}$$

The two simulink models separately using reactive power compensators SVC and STATCOM are designed. The proportional-integral (PI) controller scheme is used for control mechanism in both the compensators. For SVC, the incremental change in reactive power depends upon V, C^{BSV} while for STATCOM, the incremental change in reactive power α. The corresponding transfer equation of the SVC is given depends upon V, below

$$Q_{SVC} = K_{A4} \ C^{BSV} + K_{A5} \ V(s) \tag{6}$$

The STATCOM transfer equation is given by

$$Q_{STATCOM} = K_{B4} \ \alpha + K_{B5} \ V(s) \tag{7}$$

The transfer function block diagrams of the isolated wind-diesel power system conFigureurations for reactive power control at constant slip operation of the induction generator is shown in Figure 2. The details of all constants in equation (3) to (7) are given in the Appendix. The constant K_3 is replaced by K_{31}, and K_{32} in the case of wind-diesel-microhydro system as induction generators are used with wind and microhydro sources.
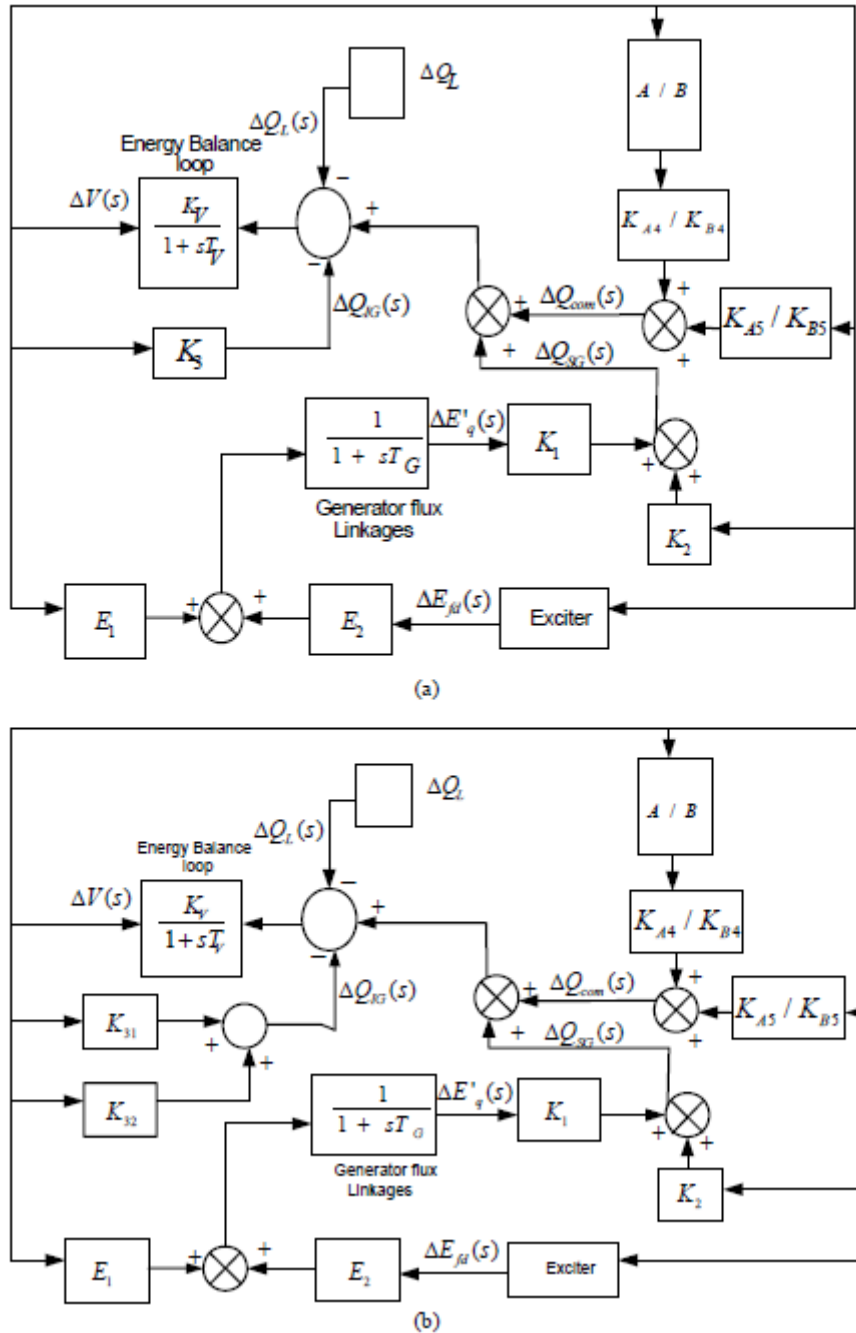
Figure 2. Transfer function block diagrams for (a) isolated wind-diesel power system (b) wind-diesel-micro-hydro- power system at constant slip operation (A: SVC, B: STATCOM)

Simulation Results

The wind-diesel system and wind-diesel-microhydro system has been simulated by using the system data as given in the Appendix. The gains K_P and K_I of the PI controllers of SVC and STATCOM have been optimized using integral square error (ISE) criterion. The optimum values obtained for the wind-diesel system are $_{KP}$ = 233, K_I =10312 for SVC controller and K_P=35, K_I=5238 for STATCOM controller and the values for the wind-diesel-microhydroare K_P = 250 and K_I = 9642 for SVC controller and K_P = 40 and K_I = 5972 for STATCOM controller. The gains have been optimized for a realistic type of disturbance in reactive power load. The transient responses for realistic disturbance for wind-diesel system with SVC are shown in Figure 3. It has been observed that the system voltage decreases as the load increases. Initially, synchronous generator and the SVC supplies the reactive power required by the system. Finally, the voltage regulator of the synchronous generator maintains the voltage by eliminating the deviation in

voltage. But the reactive power required by the load is suppliedby the SVC under steady state conditions as shown in Figure 3 (d). It has been observed that the oscillations following the disturbance settle down in approximately 0.0225 seconds. Similarly, the transient responses for realistic disturbance in reactive power load for wind-diesel system with STATCOM are shown in Figure 4. Again it has been observed that the increase in reactive power load is supplied by the STATCOM under steady state conditions. Comparing Figure 3 and Figure 4, it has been observed that peak deviations in the system voltage are less in case of STATCOM than that of SVC. It has also been observed that the settling time of oscillations following the disturbance is approximately 0.01 seconds which is considerably less that of SVC.
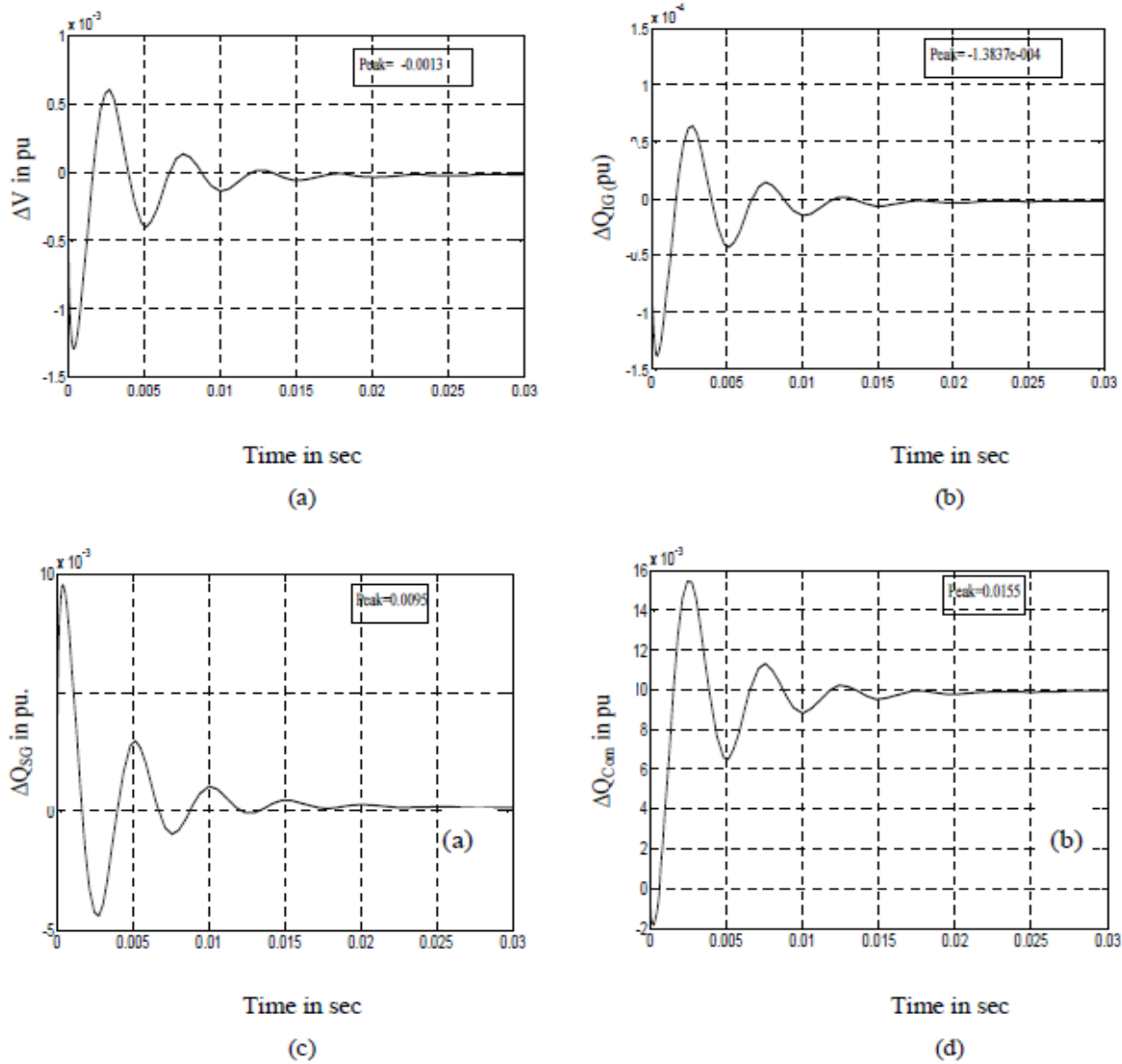

Figure 3. Simulation results: Transient responses of the *wind-diesel system with SVC* for realistic disturbances in reactive power load showing time vs. (a) ΔV, (b) *IG* ΔQ, (c) *SG* ΔQ, and (d) *com*

CONCLUSION

The reactive power control of isolated wind-diesel and wind-diesel-microhydro systems has been investigated in this paper. The controlled reactive power has been investigated by using STATCOM and SVC. The system has been simulated by taking typical data and the gains of the controller have been optimized. A realistic disturbance i.e. 1% step increase in reactive power load plus band limited white noise has been considered. It has been shown that STATCOM is a betterchoice for damping transient oscillations due to disturbances in the system than the SVC.

ACKNOWLEDGEMENT

REFERENCES

[1] Ray Hunter, George Elliot, 'Wind-Diesel Systems, A Guide to the Technology and its Implementation,' (Cambridge University Press, 1994).

[2] H. Nacfaire, 'Wind-Diesel and Wind Autonomous Energy Systems', in (ed.), (Elsevier Applied Science, London, 1989).

[3] N. G. Hingorani , L. Gyugyi, 'Understanding FACTs: Concepts and technology of Flexible AC Transmission Systems', (*IEEE Power Eng. Soc., New York, 2000*).

[4] A. A. F. A1-Ademi, 'Load-Frequency Control of Stand-Alone Hybrid Power Systems Based on Renewable Energy Sources', Ph. D Thesis, Centre for Energy Studies, Indian Institute of Technology, Delhi (India), July 1996.

[5] R. C. Bansal, T. S. Bhatti, and D. P. Kothari, 'A bibliographical survey on induction generators for application of non-conventional energy systems', *IEEE Trans. Energy Convers.,* 18(2003)3, pp. 433–439.

[6] K. Tandon, S. S Murthy, and G. J. Berg, 'Steady State Analysis of Capacitors Excited Induction Generators', *IEEE Transactions on Power Apparatus and Systems*, 103 (1984)3.

[7] S. S. Murthy, O. P. Malik, and A. K. Tandon, 'Analysis of Self-Excited Induction Generator', *IEE Proceedings*, 129 (1982)6.

[8] B. T. Ooi, R. A. David, "Induction Generator/Synchronous Condenser System for Wind Turbine Power", *Proceeding of IEE,* Vol. 126. No. 1, January 1979.

[9] M. A. Elsharkawic, S. S. Venkata, T. J. Williams, and N. G. Butlar, "An adaptive power factor controller for Three Phase Induction Generator", *IEEE Transaction on Power Apparatus and Systems*, Vol. PAS-104, No. 7, July 1985.

[10] S. E. Haque, N. H. Malik, and W. Shepherd, "Operation of a Fixed Capacitor Thyristor Controlled Reactor (FC-TCR) Power Factor Compensator", *IEEE Transaction on Power Apparatus and Systems,* Vol. PAS-104, No. 6, July 1985.

[11] E. Hammad, "Analysis of Power System Stability enhancement by Static VAR Compensators", *IEEE Transactions on Power System,* Vol. PWRS-1, No. 4, November 1986.

[12] R. C. Bansal, "Automatic Reactive Power Control of Autonomous Hybrid Power System", Ph.D. Thesis, Centre for Energy Studies, Indian Institute of Technology, Delhi, December 2002.

[13] Bhim Singh, S. S. Murthy, and Sushma Gupta, "Analysis and Design of STATCOMbased voltage regulator for self-excited induction generators," *IEEE Transactions On Energy Conversion*, Vol. 19, No.4, 2004, pp.783-790.

[14] B. Singh, and L. B. Shilpakar, "Analysis of a novel solid state voltage regulator for a selfexcited induction generator," *Proc. Inst. Elect. Eng.,Gen., Transm*. Dist. Vol. 145, No.6, pp. 647-655, 1998.

[15] E.G. Marra, and J. A. Pomilio, "Self-excited induction generator controlled by a VSPWM converter providing high power-factor current to a single-phase grid," *Proc. Industrial Electronics Society Conf*, pp. 703-708, 1998.

[16] S. C. Kuo, and L. Wang, "Analysis of voltage control for a self-excited induction generator using a current-controlled voltage source inverter (CC-VSI)," *Proc. Inst. Elect Eng., Gen., Transm. Distrib*, Vol.148, No.5, pp. 431–438, 2001.

[17] E. Larsen, N. Miller, S. Nilsson, and S. Lindgren, "Benefits of GTO-based compensation systems for electric utility applications," *IEEE Trans. Power Delivery*, Vol.7, 1992; pp.2056–2063.

[18] B. Kouadri, Y. Tahir, "Power flow and transient stability modeling of a 12-pulse statcom, *Journal of Cybernetic and Informatics*," Vo. 7, pp. 9-25, 2008.