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Reactive Power Control of Wind & Diesel Hybrid System using SVC and STATCOM

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Abstract

For the development of modern society electricity is one of the important ingredients. However, everyone in this world is not lucky enough to have access to electricity. It may be due to remoteness, cost, or non-availability of sufficient grid power especially in the developing countries. The most common way to supply electricity to remote area loads is with diesel power plants. The main advantage of diesel system is that it is extremely proven technology and it is highly reliable, if maintained properly. The cost of electricity can be made comparable with the grid power by integrating diesel systems with other non-conventional energy systems (wind, small hydro, P.V. etc.) depending upon sitting conditions. In the proposed system, the wind–diesel autonomous system is considered for reducing diesel fuel cost by tapping wind energy potential, which is inexhaustible and available in abundance all over world. However, the intermittency associated with wind may affect the quality of supply considerably and even may damage the system in the absence of proper control mechanism. In any electrical power system network, especially in autonomous system, the main parameters to be controlled are the system frequency and voltage, which determine the stability as quality of the supply. In a power system, frequency deviations are mainly due to the real power mismatch between generation and demand, whereas voltage mismatch is the sole indicator of reactive power unbalance in the system, in the power system active power balance can be achieved by controlling the generation. Reactive power balance in hybrid system can be obtained by making use of the variable reactive power device e.g. Static VAR Compensators (SVC), Static Compensator (STATCOM). In this proposed work, a wind–diesel hybrid system is modeled and simulated while controlling main parameters of the system frequency and voltage, which is very crucial for system stability. Voltage miss match is the sole indicator of reactive power unbalance in the system. In this work, a step disturbance is applied to wind–diesel hybrid system, which disturbs the system frequency and voltage. Therefore, a thorough investigation on wind–diesel hybrid system has been performed under stepped disturbance. First, we have considered an IEEE type-I excitation system connected to wind–diesel hybrid system for controlling its terminal voltage, which is found to insufficient proper voltage control. However, SVC and STATCOM are considered to be more efficient in meeting out any sudden change in reactive power demand and a better control of the terminal voltage may be easily obtained. The Secondary source to control the reactive power of wind–diesel hybrid system we have taken SVC and STATCOM in which STATCOM give batter performance. That have been thoroughly studied and simulated.

Keywords: *Autonomous System, MATLAB, STATCOM.*

Introduction

A power system which can generate and supply power is called by various names as remote, decentralized, stand-alone, autonomous, isolated power system, etc. The most common way to supply electricity to loads is with diesel power plants. The main advantages of diesel system are that it is extremely proven technology and it is highly reliable if maintained properly. The major disadvantage with diesel network is that the cost of electricity is very high which is mainly due to the cost of fuel, transportation cost and cost of operation and maintenance. The cost of electricity can be made comparable with the grid power by integrating diesels systems with other non-conventional energy systems (wind, small hydro, P.V., etc.) depending upon sitting conditions [1, 2]. This system will have additional advantages of reduction in size of diesel engine and battery storage system, saving in the fuel and reduced pollution.

Generally, in an autonomous hybrid power system, the wind/hydro power generators are main constituents of the system and are design to operate in parallel with local grids [3]. The main reasons are to obtain the economic benefit of no fuel consumption by wind/hydro turbines, enhancement of power capacity to meet the increasing demand, to maintain the continuity of supply in the system. Wind is highly fluctuating in nature and it will affect the quality of supply considerably and even may damage the system in the absence of proper control mechanism. Main parameters to be controlled are the system frequency and voltage, which determine the stability and quality of the supply.

In a power system, frequency deviations are mainly due to real power miss match between generation and demand, whereas voltage miss match is the sole indicator of reactive power unbalance in the system, in the power system active power balance can be achieved by controlling the generation i.e. by controlling the fuel input to diesel electric unit this is called automatic generation control or load frequency control or management of output power [4]. Reactive power balance in the hybrid system can be obtained by making use of variable reactive power device e.g. Static VAR Compensators (SVC) and Static Compensator (STATCOM).

It is assumed that the load frequency control and excitation control are non-interactive as small changes in active power [5–7] are mainly dependent on changes in generator speed and are almost independent of changes in terminal bus voltage, while small changes in terminal voltage are mainly dependent on machine excitation and almost independent of change in generator speed [8]. Furthermore, the excitation control is fast acting with a major time constant encountered is that of the generator field while frequency control is slow acting with major time constant is contributed by turbine and moment of inertia of the generator. The later time constant is much larger than that of the generator field. Therefore, the load frequency control loop and load voltage control loop are assumed to be decupled in conventional power system [9–11].

Wind System

Among the renewable sources of energy available today for generation of electric power [12, 13], wind energy stands for most because of the no population, relatively low capital cost evolved and the short the gestation period. Recently wind turbine of 4.5MW and rotor diameter of more than 112.8 meter has been in operation. Today wind energy is the fastest growing source. At present wind power accounts for 0.4% of world elect city demand. An analysis by European wind energy association (EWEA) [5] shows that there are no technical, economic or recourse limitation that prevent wind power [14, 15] from developing to nearly 12% of the world's electricity supply by 2020, but with strong political commitment worldwide wind energy industry could install and an estimated 1200,000 MW by 2020.

Types of Wind System **Windmill scale**	**Rotor diameter**	**Power rating**
Micro	<3 m	50 W to 2 kW
Small	3 to 12 m	2 to 40 kW
Medium	12 to 45 m	40 to 1000 kW
Large	>45 m	>1 MW

Diesel generator (DG) Set

A DG set (a unit of diesel engine and generator) is a device which converts fuel (diesel oil) energy into mechanical energy in diesel engine and subsequently convert mechanical energy into electrical energy in a generator [16, 17]. A diesel can be two or four strokes. The speed diesel engine is generally related to size with large engine tending to operate at lower speeds usually at 900 rpm. Higher speed engines are more common in the small to medium size range. Common speeds are 2400, 3000 and 3600rpm which are suited to normal operating speeds of generator. Engine governor control the engine speeds, which regulates the frequency of generators. Governor could be mechanical or electrical type. Synchronous generates are equipped with appropriate excitation systems to maintain the voltage with specified limits.

Advantage of Combination of Wind–Diesel System

A wind–diesel hybrid combines wind turbine with diesel generator to obtain a maximum power contribution by the intermittent wind resource while providing continuous high quality electric power. The benefits of hybrid system are reduced system operating costs and reduced environmental impacts.

Need for Reactive Power Control

- To improve voltage regulation.
- To enhancement of steady state and dynamic stability.
- To reduction of over voltages/under voltages.
- To reduction in voltage unbalance.

Reactive Power Control of Wind–Diesel Hybrid System

- In any hybrid energy system, there may be more than one type of electrical generators [18]. An induction machine will run as an induction generator when it is operated above synchronous speed. If an appropriate capacitor bank is connected across externally driven induction generator, an e.m.f. induced in the machine winding due to excitation provided by the capacitor. The main disadvantage of the induction generator is that it requires reactive power support for it operation. In case of grid-connected system induction can get power from grid, where as in case of isolated system reactive power can only supplied by capacitor banks. In addition, most of the loads are also inductive in nature, therefore the mismatch in generation and consumption of reactive power can cause serious problem of large voltage fluctuations at terminals at generator terminals especially in an isolated system. The terminal voltage of the system will sag if sufficient reactive power is not provided, whereas surplus reactive power can cause high voltage spikes in the system, which can damage the consumer's equipment.

Basic Operation of Wind–Diesel Autonomous System

A hybrid system is typically up to a few MW. The stand-alone wind–diesel system maybe ranging from a10 kW wind turbine operated in conjunction with a 5 kW DG set up to several MW wind turbines/diesels. Figure 1 shows a typical simplified wind–diesel hybrid system with main components.

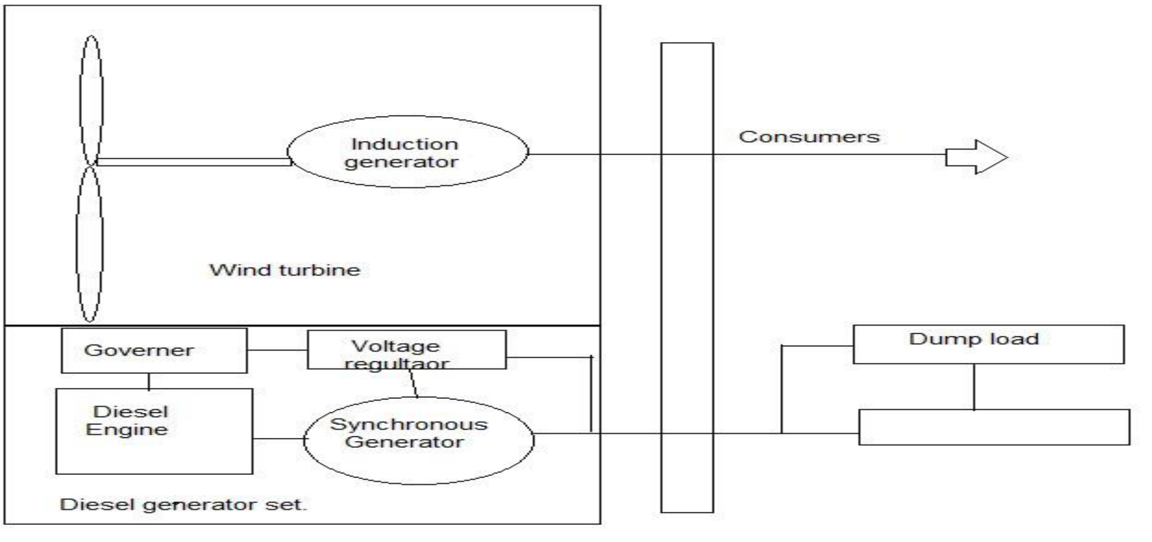

Figure 1: Functional diagram of wind–diesel system

In a wind–hybrid system, the certainty of meeting load demands at all time is greatly enhanced using more than one power source [19]. Besides using diesel generator with wind turbine for electrical generation, batteries are used to meet the daily load fluctuation in short terms and diesel generator are used to meet long term load fluctuation. Grid connected wind energy conversion system influences the system to certain extent due to varying power output from the wind energy conversion system. On a large interconnected grid system, this is seen mainly in localized voltage variations and fluctuations on a variety of time scales, from voltage waveform harmonics through flicker to long-term voltage variations. As a result, a wind/diesel scheme strategy will be required, such as energy storage or load control, so than sudden drops in wind power can be buffered in one way or another. The classic wind–diesel hybrid system is based on the combination of fossil fuel engine generators and wind turbines usually alongside ancillary equipment such as energy storage, power convertors and various control equipment, to generate electricity hybrid power system are designed to increase capacity and reduce the cost and environmental impact of electrical generation at remote places and facilitates that are not linked to the public power grid [20]. If wind conditions are sufficient wind–diesel system can lower cost of electricity reducing reliance on diesel fuel for remote communities.

Main Components of Wind–Diesel Hybrid System

Following are the main components of wind–diesel hybrid system.

1. Diesel generator set
2. Induction generator
3. Synchronous generator
4. Structure of wind energy conversion system

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Model of Static VAR Compensator (SVC)

Figure 2 shows model of SVC.

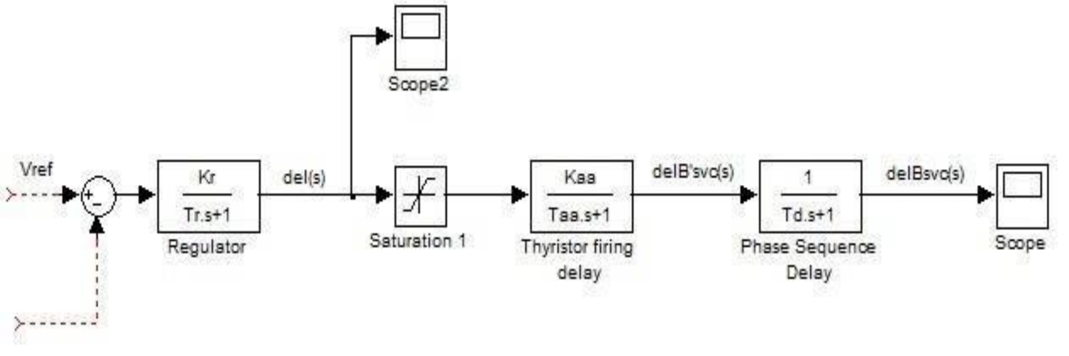

Figure 2: Model of static VAR compensator (SVC)

Model of STATCOM

The active power demand of load is fulfilled by the synchronous generator and the induction generator. The reactive power required for operation of the induction generator and load is provided by synchronous generator and STATCOM. Figure 3 shows model of STATCOM.

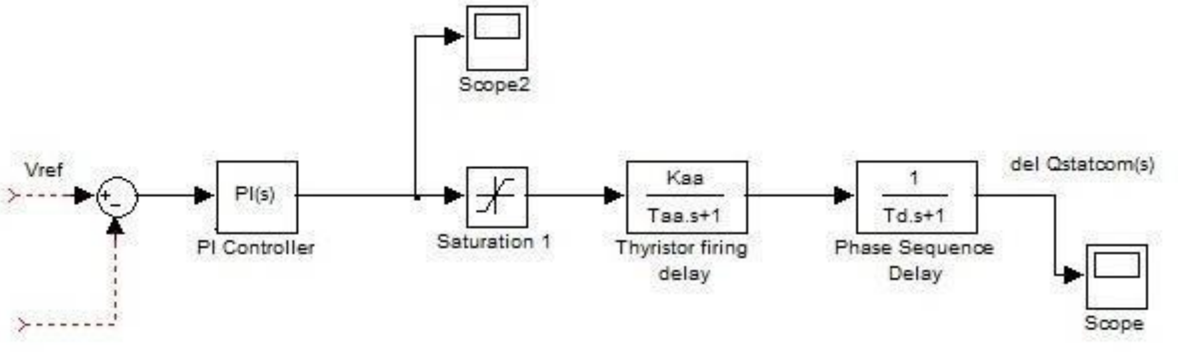

Figure 3: Model of STATCOM

IEEE Type-I Excitation Control System

Figure 4 shows transfer function model of IEEE type-I excitation system.

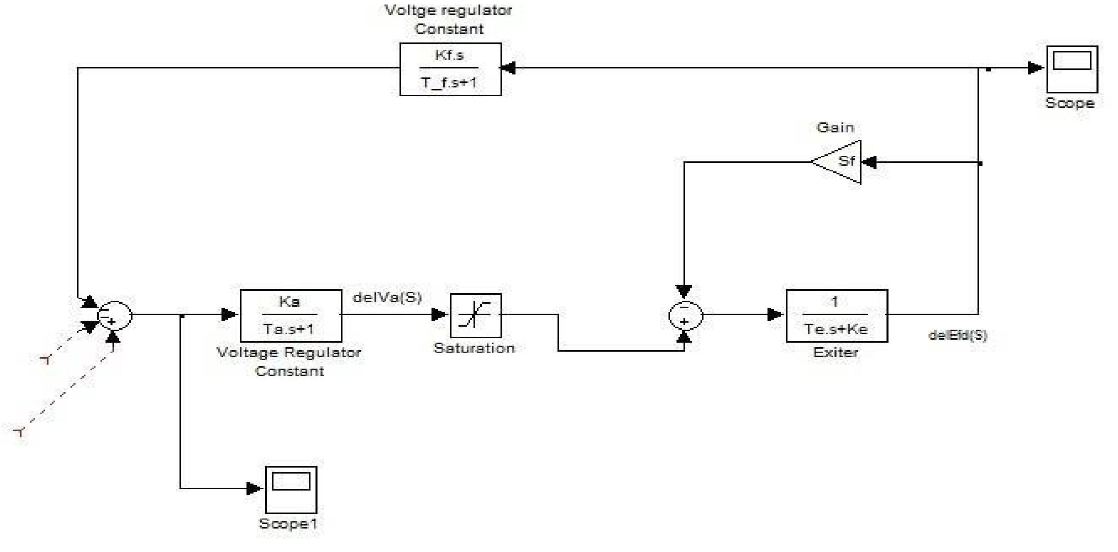

Figure 4: Transfer function model of IEEE type-I excitation system

Simulation of Wind–Diesel Hybrid System using Matlab/Simulink Working with Models

Simulink lets you to create, model, and maintain a detailed block diagram of the system using a comprehensive set of predefined blocks. Simulink software includes an extensive library of functions commonly used in modeling a system. These include Continuous and discrete dynamics blocks, such as Integration and Unit Delay Algorithmic blocks, such as Sum, Product, and Lookup Table Structural blocks, such as MUX, Switch, and Bus Selector. It is possible to customize these built-in blocks or create new ones directly in Simulink and place them into new libraries. Additional block sets (available separately) extend Simulink with specific functionality for aerospace, communications, radio frequency, signal processing, video and image processing, and other applications. Figure 5 shows Simulink Library Browser.

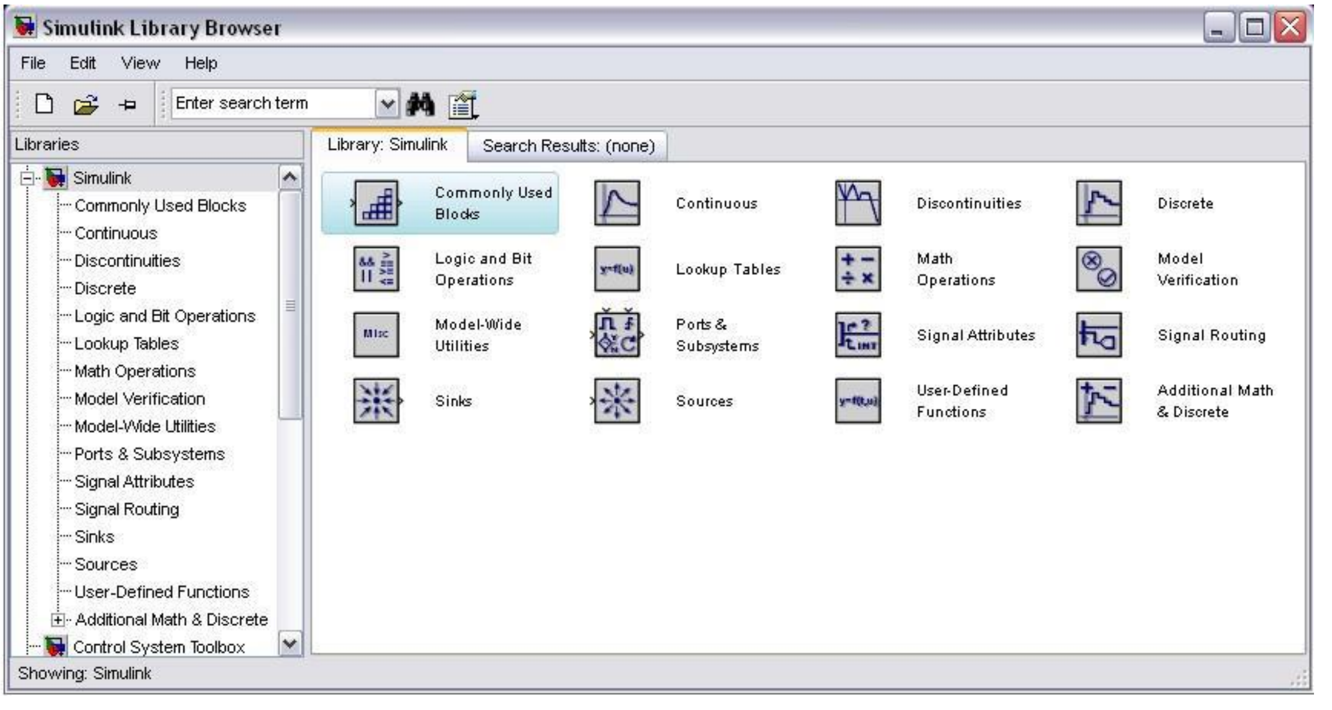

Figure 5: Simulink Library Browser

Creating and Running Models

When you incorporate MATLAB code, you can call MATLAB functions for the data analysis and visualization. With Simulink, you build models by dragging and dropping blocks from the library browser onto the graphical editor and connecting them with lines that establish mathematical relationships between the blocks. You can arrange the model by using graphical editing functions. After building your model in Simulink, you can simulate its dynamic behavior and view the results live. Comparisons of the outputs waveforms from the various Simulink models are made in order to determine the most suitable model for the location and the given load profile.

Modeling of Wind–Diesel Hybrid System

The function of load frequency controller is to eliminate a mismatch created either by small real power load change or due to change in input wind power. The input power to wind power generating unit is not controllable in the sense of generation control, but a supplementary controller, known as load frequency controller, can control the diesel power generating unit and, thereby, of the system. The small real power mismatch causes a perturbation about the nominal operating point, and therefore the system dynamics may be described by linear differential equations. The transfer function block diagram of the isolated wind–diesel system is shown in Figure 6 which includes the load frequency controller and also the blade pitch controller the dynamics of the wind power generating unit is described by a first order system. A higher order model can, however, be considered if the slow dynamics of the mechanical parts are to be incorporated. The continuous time dynamic behavior of the load frequency control system is modeled by a set of state vector differential equations (Table 1).

Simulink Model of Wind-Diesel Hybrid System

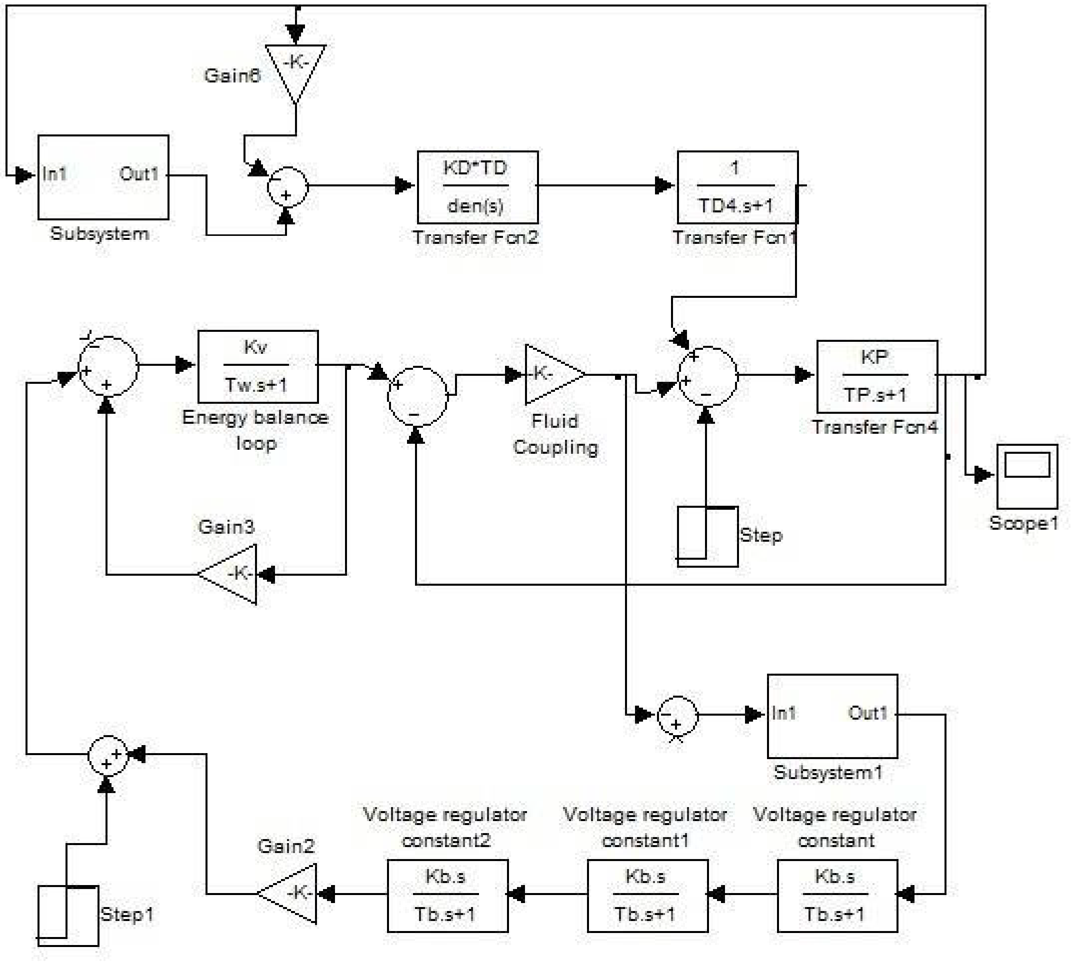

Figure 6: Transfer function blocks diagram representation of basic isolated wind–diesel hybrid system with controllers

Rating and Data of Isolated System

Table 1: Rating and data of isolated system data

Sr. No.	Rating and data of isolated system data. Generation capacity		Load	System Parameters				
	Wind Gen.	diesel Gen.	kW	Kp	Tp	Kig	Ktp	Kgh
wind-diesel	150	150	150+100 =250	72	14.4	1.924	0.0040	-

Transfer-Function Block Diagram of Wind–Diesel Hybrid System Using SVC

Figure 7 shows transfer-function blocks diagram for the reactive-power control of the wind–diesel hybrid system with SVC and IEEE Type-I excitation.

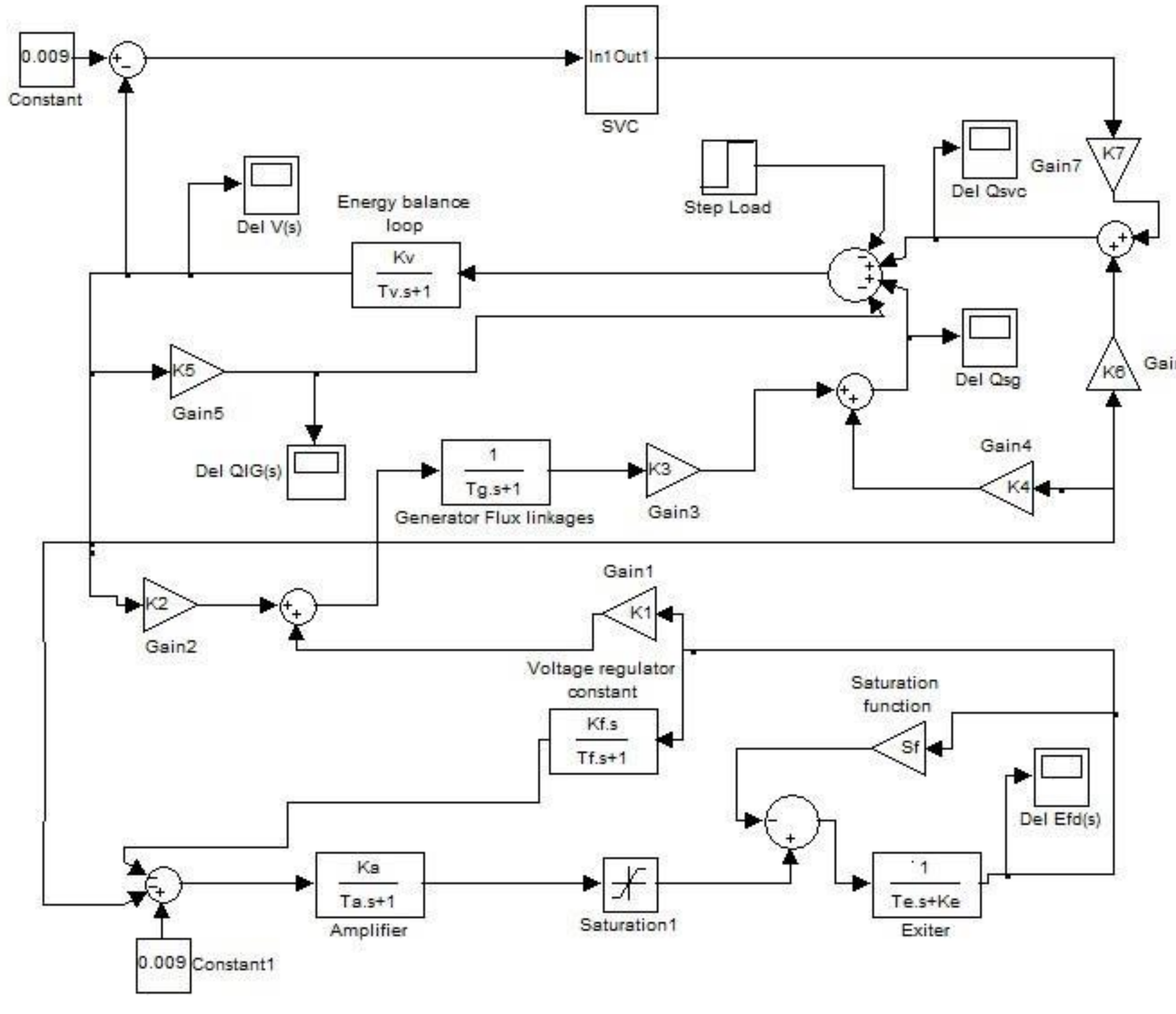

Figure 7: Transfer-function blocks diagram for the reactive-power control of the wind–diesel hybrid system with SVC and IEEE TYPE-I excitation

Transfer-Function Block Diagram of Wind–Diesel Hybrid System Using STATCOM

Figure 8 shows transfer-function block diagram for the reactive-power control of the wind–diesel hybrid system with STATCOM and IEEE TYPE-I excitation.

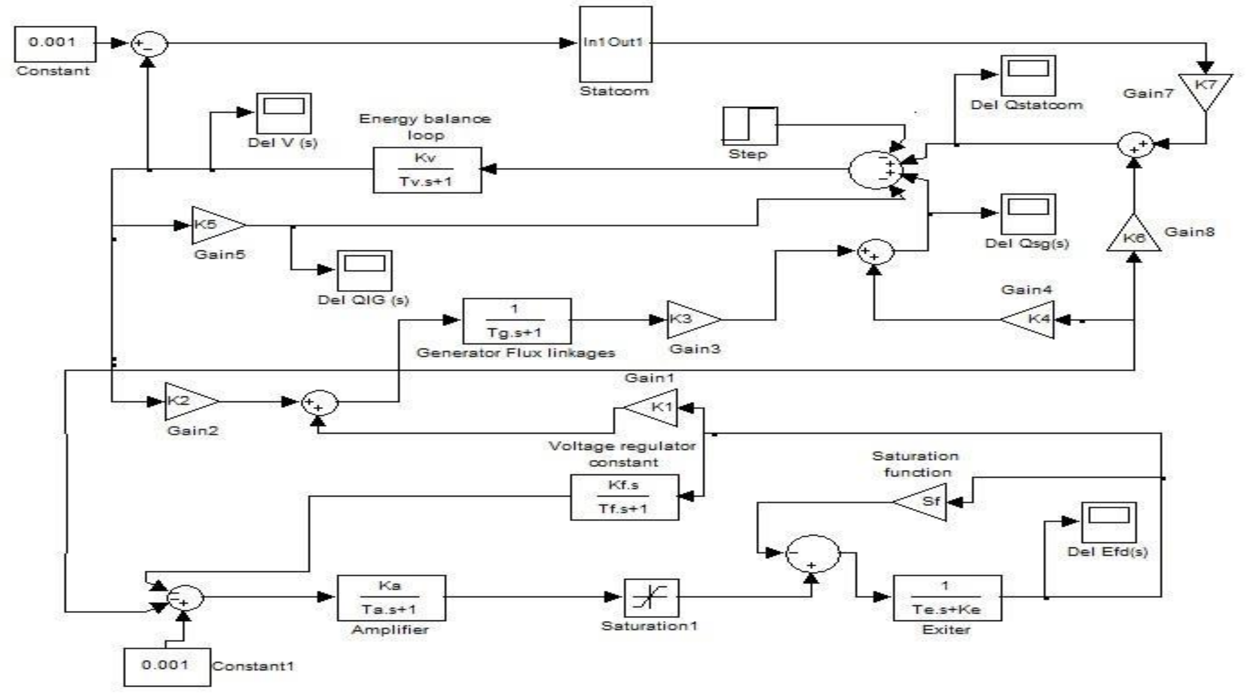

Figure 8: Transfer-function block diagram for the reactive-power control of the wind–diesel hybrid system with STATCOM and IEEE TYPE- I excitation

Results and Discussion

Transient Responses of the Wind–Diesel Hybrid System with Static VAR Compensator (SVC): Figures 9–13 show the simulation result of wind–diesel hybrid system using SVC FACTS device. The results are p.u. change in exciter voltage, p.u. change in reactive power generated by diesel generator, p.u. change in reactive power generated by induction generator, p.u. change in voltage and p.u. change in reactive power generated by compensator with respect to the settling time.

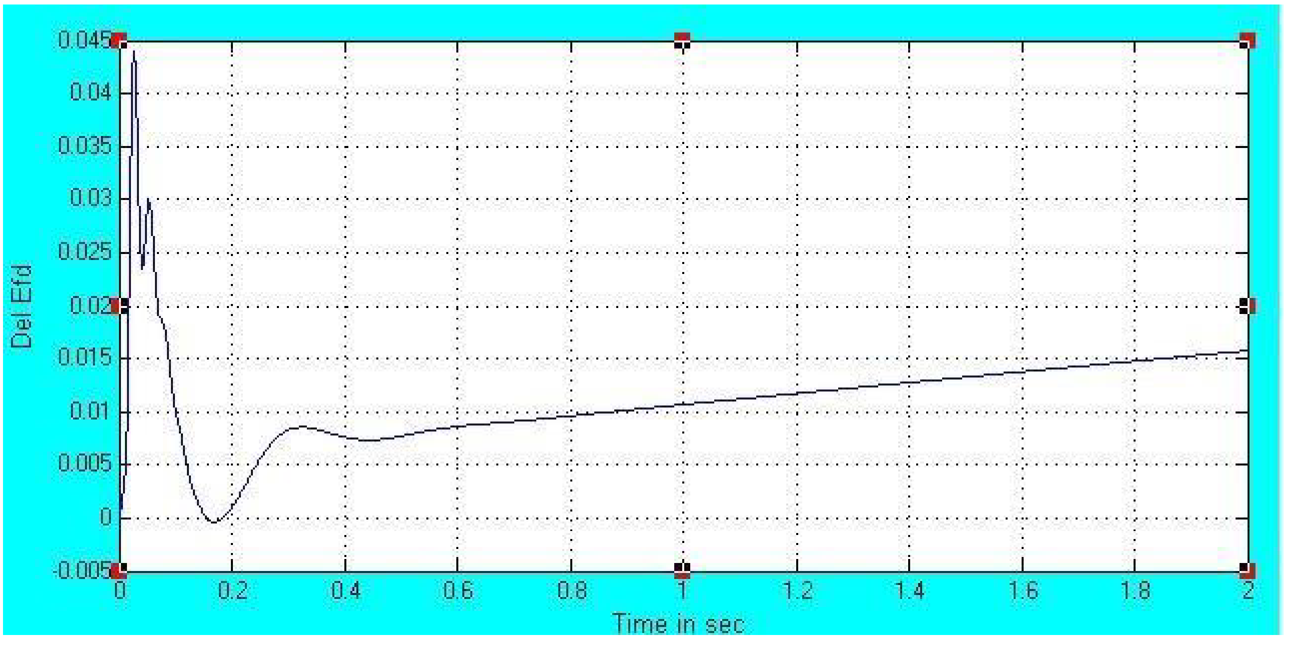

Figure 9: Transient response of the wind–diesel hybrid system with SVC for step disturbance, p.u. change in exciter voltage (ΔEfd) vs time

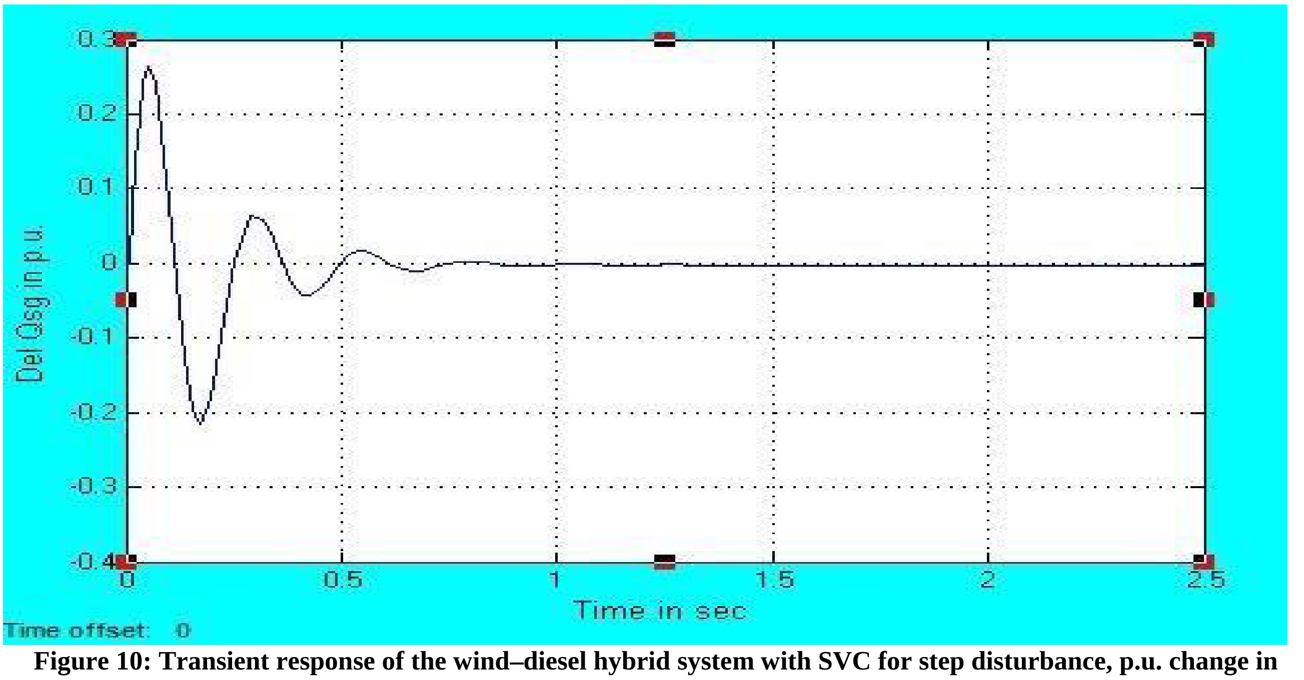

Figure 10: Transient response of the wind–diesel hybrid system with SVC for step disturbance, p.u. change in reactive power generated by diesel generator (ΔQSG) vs time

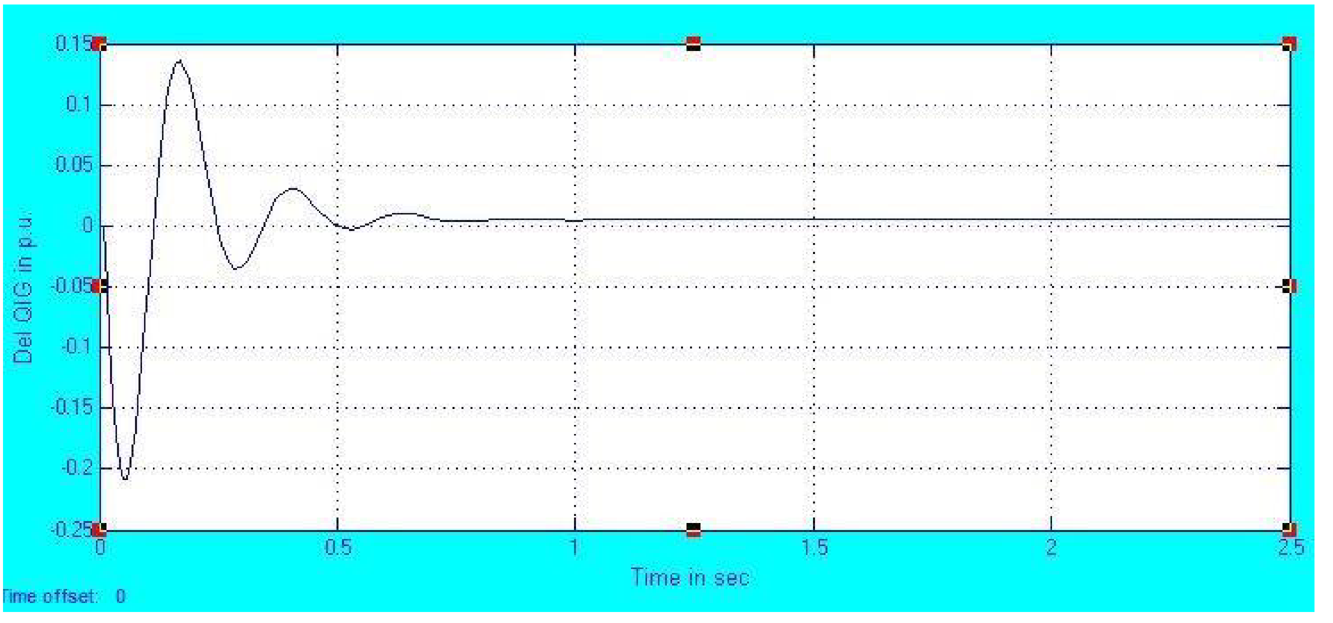

Figure 11: Transient response of the wind–diesel hybrid system with SVC for step disturbance, p.u. change in reactive power generated by induction generator (ΔQIG) vs time

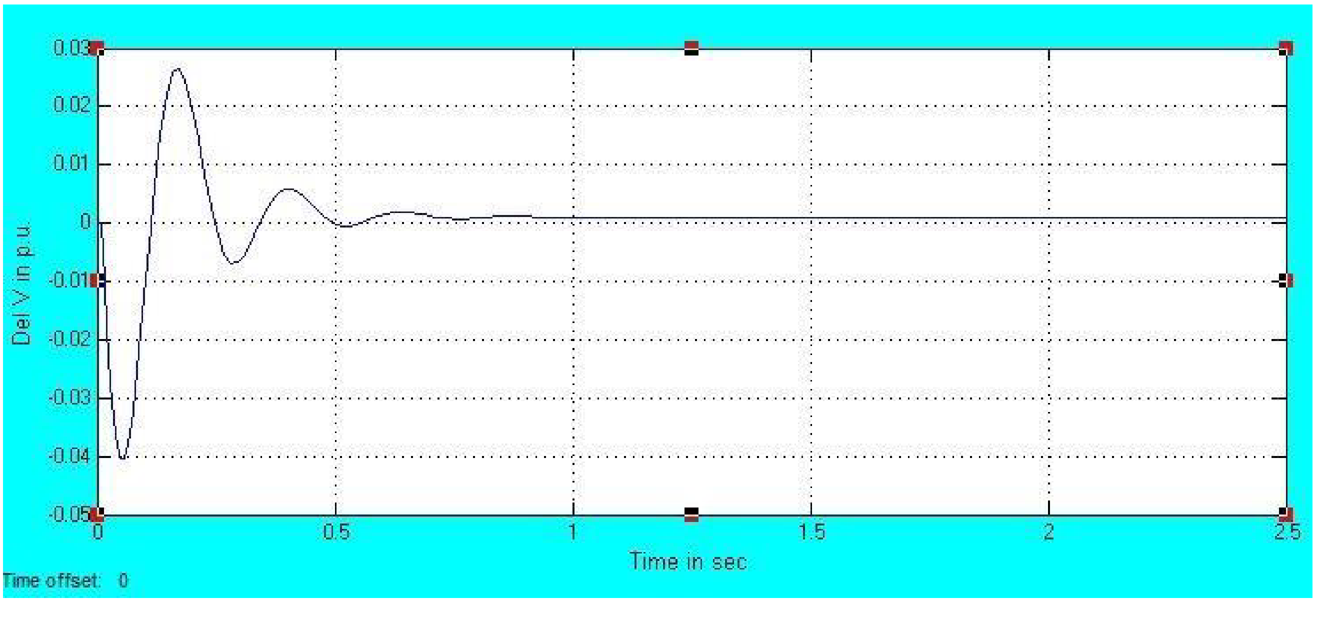

Figure 12: Transient response of the wind–diesel hybrid system with SVC for step disturbance, p.u. change in voltage (ΔV) vs time

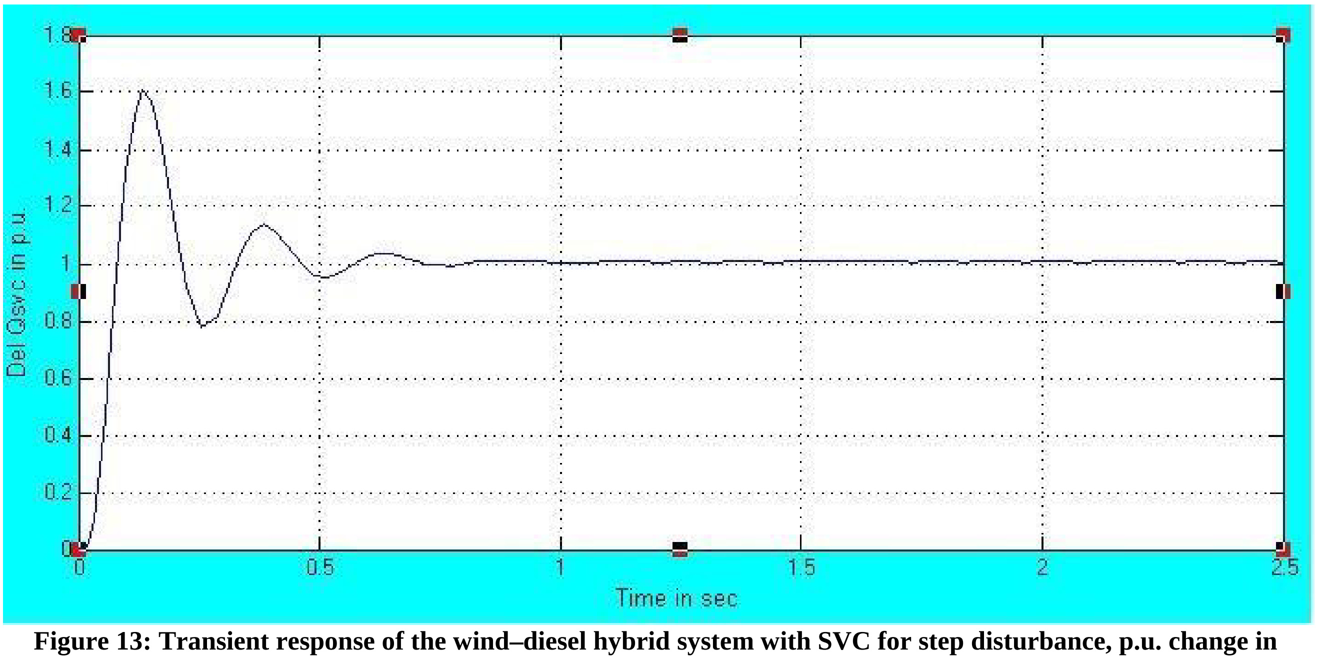

Figure 13: Transient response of the wind–diesel hybrid system with SVC for step disturbance, p.u. change in reactive power generated by compensator (ΔQsvc) vs time

Conclusion

The reactive power control of isolated wind–diesel hybrid system has been investigated in this thesis work. The controlled reactive power has been investigated by using SVC and STATCOM. The system has been simulated by taking typical data and the gains of the controller have been optimized. A step disturbance i.e. 1% step increase in reactive power load. Dynamic voltage stability study has been presented in this thesis work for the isolated wind–diesel hybrid system. Considering a transfer function model based on a small signal analysis. The automatic reactive power control model using reactive power control flow equations have been developed for SVC and STATCOM. It can be seen that STATCOM performance is best in comparison to SVC. The waveform settling time of STATCOM is less than the SVC. Dynamic voltage stability has been studied for isolated wind–diesel hybrid system considering a transfer function model based on small signal analysis. It has been shown that STATCOM is a batter choice for reactive power control due to disturbance in the system than SVC.

Future Scope

Although this research has covered most of the interesting issues and challenges of the advanced in controlling reactive power using SVC and STATCOM. But there are certain aspects that might be interesting for future investigations among the renewable sources of energy available today. In future, the other source of renewable sources of energy may be optimized using advanced FACTS devices like TSSC, TSSR, TCBR, ASTATCOM, UPFC, IPFC, SSSC, etc. For generation of electric power recently wind turbine of 4.5 MW and rotor diameter of more than 112.8 m has been in operation. Today wind energy is the fastest growing source. At present wind power accounts for 0.4% of world electricity demand. An analysis by European Wind Energy Association (EWEA) shows that there are no technical, economic or recourse limitation that prevent wind power from developing to nearly 12% of the world's electricity supply by 2020, but with the strong political commitment worldwide wind energy industry could install and an estimated 1200,000 MW by 2020. Different AI techniques may also be implemented for better results in future.

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