STUDY OF HYBRID ENERGY SYSTEM BASED ON WIND-DIESEL ENGINE SYSTEM

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STUDY OF HYBRID ENERGY SYSTEM BASED ON WIND-DIESEL ENGINE SYSTEM

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in “Electrical Engineering”

By

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CERTIFICATE

This is to certify that the thesis titled "**Study of Hybrid Energy System based on Wind-Diesel Engine System**", submitted to National Institute of Technology, Rourkela by **Mr. Samresh Satapathy, Roll No. : 110EE0227** for the award of **Bachelor of Technology** in **Electrical Engineering** is a bonafide record of research work carried out by him under my supervision and guidance.

The candidate has fulfilled all the prescribed requirements.

The thesis which is based on the candidate's own work, has not been submitted elsewhere for a degree/diploma.

In my opinion, the thesis is of standard required for the award of a **Bachelor of Technology** in Electrical Engineering.

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I am blessed by my parents, who instilled within me a love of creative pursuits, science and language, all of which finds a place in this report.

Samresh Satapathy

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With Blessings from Almighty

Dedicated to

My Parents.

ABSTRACT

The aggravated increase in energy demand has posed a serious problem for the power system's stability and reliability, and hence has become of major concern. The shortcomings of conventional source of energy have paved way for renewable energy sources. The latter can form a part of a stand-alone system or grid connected system. A single renewable source of energy when integrated with other sources of energy it is termed as hybrid system. This thesis deals with wind-diesel engine system. Wind diesel hybrid systems (WDHS) obtain maximum contribution from wind and rest by diesel generators. They are handy for rural or island areas.

In this thesis an active power control strategy has been developed such that when the wind alone is not able to meet the energy demand, without compromising the frequency a transition occurs to wind diesel mode so that the energy demand is met. Then the system's dynamic performance is compared for two cases with squirrel cage induction generator and permanent magnet induction generator. The mathematical model considered uses a STATCOM to meet the reactive power need upon sudden step change in power. The performance and the analysis is done in a user friendly MATLAB/Simulink environment.

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ABBREVIATIONS AND ACRONYMS

DG	**Distributed generation**
PV	Photo voltaic
BESS	Battery based energy storage system
SM	Synchronous machine
WDHS	Wind diesel hybrid system
PMIG	Permanent magnet induction generator
PMSG	Permanent magnet synchronous generator
IG	Induction generator
WTG	Wind turbine generator
DE	Diesel engine
PID	Proportional, integral, derivative
DO	Diesel only
WO	Wind only
WD	Wind diesel
STATCOM	Static synchronous compensator
MATLAB	MATrix LABoratory

CHAPTER 1

Introduction

1.1 MOTIVATION

Power quality and reliability have become a crucial factor for the development of new technologies with the imminent deregulated environment. Distributed generation (DG) systems are expected to play a major role to meet the energy demand with clean environment. DG technologies such as photovoltaic systems, wind turbine, fuel cell, diesel engines are used in various places [1]. Wind energy has received the special attention of researchers in recent times. The advent of power electronic devices have steered a new era of power quality while integrating them with the renewable sources of energy. The renewable systems can either be interfaced with the existing grids or can be operated on a stand-alone basis. Effective capture of wind energy can definitely help to meet the energy needs as is evident in countries such as Germany, Netherlands, Canada etc. Stand alone or isolated systems are common in islands or far rural areas where the utility grid can’t reach.

A single renewable energy source may not be able to meet the load demands apart from the fact that continuous supply of energy may not be ensured (say wind is not available on a particular day in a wind farm). This makes the importance of hybrid energy systems such as wind- PV, wind-diesel along with use of battery etc. Owing to the fast controllability and response time of the diesel engines, they are quite popular for integration with wind energy conversion systems (WECS). Hence a wind diesel hybrid system is considered in the thesis. Induction generators are utilised for wind systems. However recent technologies have paved way for other generators such as self-excited type, permanent magnet type etc. which have their relative merits and demerits which has been explored here.

1.2 BACKGROUND AND LITERATURE REVIEW

Wind diesel hybrid systems (WDHS) are autonomous systems that use wind turbine generators with diesel generators to procure utmost contribution by the sporadic wind energy to the total power generated, while ensuring uninterruptible electric power of high quality [2]. As a result the fuel consumption decreases and the overall operating cost reduces while also contributing to a green environment. Owing to low conversion efficiency of solar cells wind power is considered to be more promising among various non-conventional energy sources. The communities where grid supply isn’t available have benefitted themselves by the hybrid systems [3]. If the diesel engines is run continuously it is termed as low or medium wind penetration. They have two modes: diesel only (DO) and wind diesel (WD). Regions having sufficient wind resource can operate in the third mode i.e. wind only (WO) and hence shutting the diesel engines. Generally the wind turbines used are variable speed in nature as they have many advantages [4]. As there is restriction in frequency most diesel generators operate at constant speed. A minimum load of 30% to 40% is recommended by manufacturers so as to better the efficiency and circumvent wet tracking [5]. Sometimes battery systems are also incorporated so as to avoid frequent start/stop of diesel generators.

Several literatures have been documented on the dynamic simulation of WDHS. In [6] a storage less WDHS is simulated with special reference to transition from DO to WD mode. Simulation of storage less WDHS comprising of three wind turbines and two diesel engines is shown in [7]. Unforeseen changes in load, disconnection of the wind generators and other perturbations are discussed in it. Medium penetration WDHS is emulated in [8] with diesel generators working till their rated value so that system frequency can be controlled by speed governor. Several works have also been done on inclusion of battery based energy storage

(BESS) and inclusion of flywheels while transition from one mode to the other. The former while incorporates an ac/dc interface; the latter has advantages due to the fact that energy can directly be stored in ac form and hence eliminating the converter losses. However battery systems have their own advantage of better smoothing out transitions and provide power when there is an energy shortage.

1.3 THESIS OBJECTIVES

The objectives below are hopefully achieved in the thesis.

- To design a WDHS in MATLAB/Simulink environment.
- To analyze and design a control system for smooth change from WO to WD mode so that the system constraints are met.
- To develop a mathematical model of induction generator (IG) and permanent magnet induction generator (PMIG) for small signal analysis.
- To compare the performance of IG and PMIG for various loadings through simulations in MATLAB/Simulink environment.

1.4 ORGANISATION OF THESIS

The thesis has been organized into four chapters. The individual chapters are different from each other and are described with ample theory to grasp it and understand the simulations.

Chapter 2 deals with the basic WDHS system that exists in far communities. An appropriate control strategy has been designed for the regulation of active power and hence the frequency. The system is a high penetration system and hence a smooth shift from WO to WD mode is prophesized when there is sudden increase in load demand. Modelling of clutch is also described which helps to engage/disengage the diesel generators. A dump load has also been introduced which can take care of extra power generated and hence not to lead to over frequency. Simulation results have been then analyzed to check the validity of the control strategy.

Chapter 3 then deals with the performance investigation of the stand-alone WDHS. While the previous chapter was worked with IG, here a comparative study is done with the usage of IG and PMIG. To study the relative merits/demerits two different loading conditions are compared. First the mathematical model is developed based on small signal model. A STATCOM has been incorporated which helps to reduce the reactive power mismatch. This is essential as reactive power level decides the system voltage stability. The model is then simulated in MATLAB/Simulink and the results are analyzed.

Chapter 4 concludes the work and enlists the future work for the same. Some possible limitations in the work have also been provided. The future work that can be done to improvise the current scenario is also mentioned.

CHAPTER 2

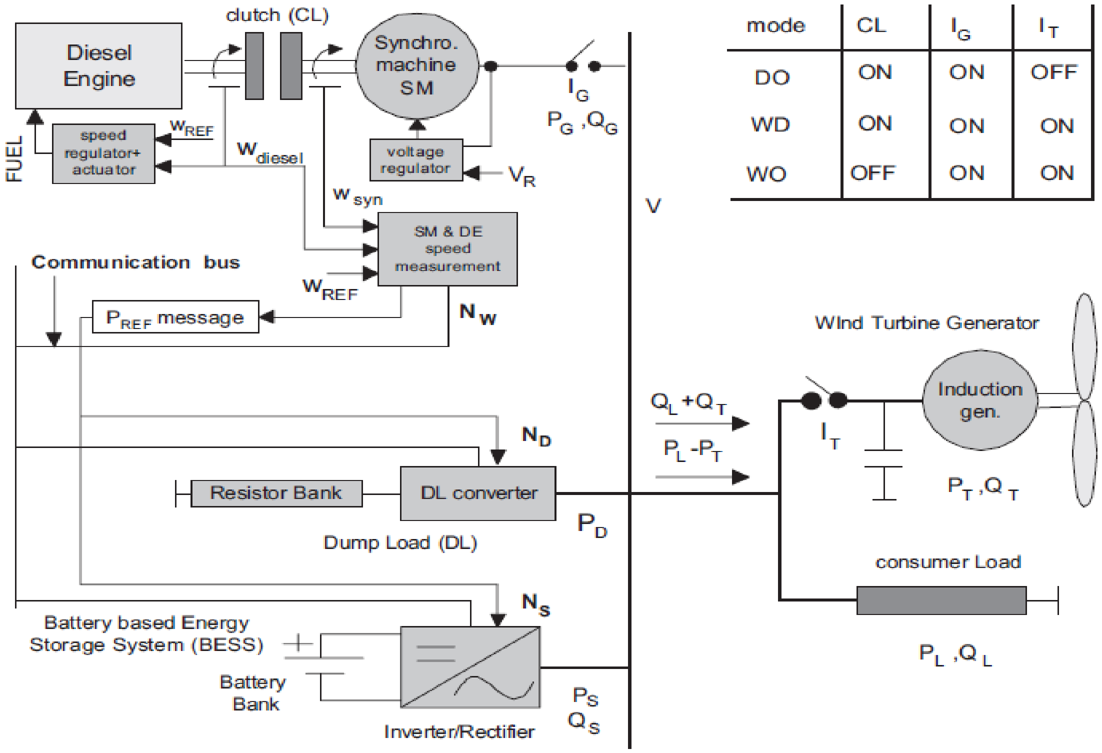
Transition from WO mode to WD mode

2.1 INTRODUCTION

The WDHS in this chapter consists of wind turbine generator (WTG), a synchronous machine (SM), the consumer load, dump load (DL), a diesel engine (DE), BESS and the discrete control system (DCS). In WO mode [9] the wind system provides the required power. When the load demand increases or wind output decreases the DCS in order to prevent the frequency collapse start the diesel engines which then meet the deficit energy demand and hence giving the name WD mode. The DE can be engaged or disengaged from the SM via clutch.

2.2 SYSTEM LAYOUT

The schematic system layout is shown in Fig 2.1.



mode	CL	I_G	I_T
DO	ON	ON	OFF
WD	ON	ON	ON
WO	OFF	ON	ON

Fig.2.1 Layout of the WDHS and DCS considered.

The clutch with the help of friction gets locked and do not slip. It helps to transmit torque to the SM from DE. Due to the isochronous nature of DE it runs at constant speed. The WTG consists of IG which runs as a constant speed stall-controlled system. The compensation capacitor bank aids for reactive power consumption by the IG. The DL which consists of a bank of resistors varies discreetly and is a controllable absorber of active power. However the BESS can act as a source or sink of active power depending on the operating conditions. The DL+BESS system perform instantaneous power balance by loading when wind power is in excess and by generating power when it is deficit. The power produced by WTG, P_T plus BESS power $P_{S\text{-}NOM}$ must be greater than load power P_L. When the constraint does not meet then the DCS starts the DE leading to WD. In this thesis it is assumed that the BESS operates at unity power factor. The component actuation is shown in table 2.1.

TABLE 2.1

Component Actuation

FUNCTION	DO	WD	WO
Active power	DG+BESS (temporary)	DG+WTG+BESS	WTG+BESS
Reactive power	SM+BESS+capacitors	As in DO	Same as DO
Control of frequency	speed regulator (DG)	As in DO	BESS+DL
Control of voltage	voltage regulator (SG)	As in DO	Same as DO

2.3 DISTRIBUTED CONTROL SYSTEM

CPU based electronic control units (called nodes) are the basic for DCS [10]. From Fig. 2.1 we see there are 3 nodes: N_D (for DL), N_S (for BESS) and N_W (speed sensor). Also the P_{REF}

message generated decides whether the auxiliary component would absorb power ($P_{REF}>0$) or supply power ($P_{REF}<0$). The droop speed control used is a PD control where the derivative part aids in increase of speed response while the proportional part loading/generating of power is done by BESS for above and under frequency respectively. The advantage of using PD controller is that it is consistent with the isochronous control of DE which is of PID type.

2.4 SIMULINK MODEL

The Simulink model is shown in Fig. 2.2.

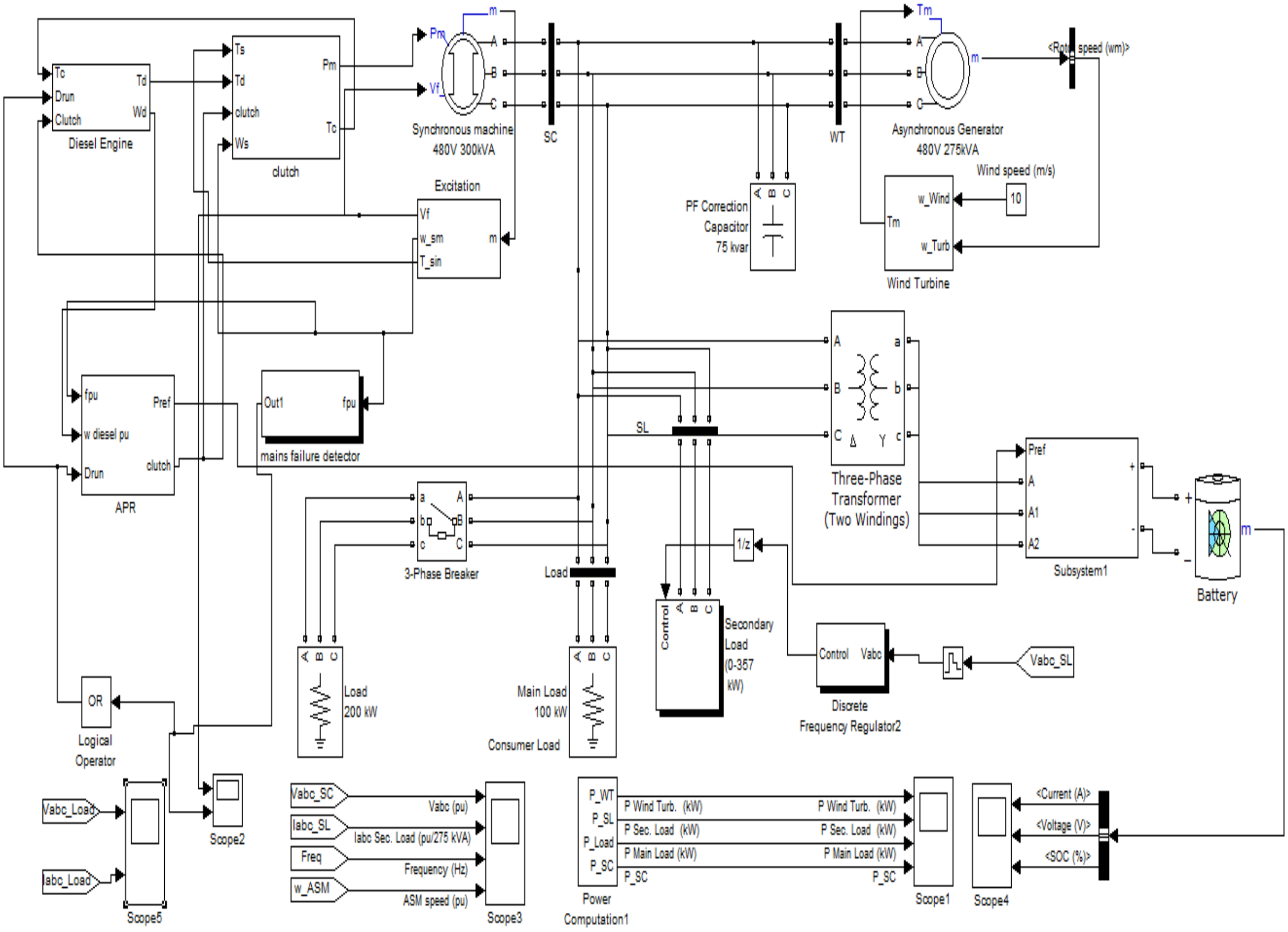


Fig.2.2. Simulink Schematic.

The nominal power of the WTG is 275KVA. There is no pitch control as it is stall controlled. The DL comprises of eight three phase resistors which can be turned on or off by GTOs connected in series [11]. DL's power consumption can be expressed as 8-bit binary progression. The subsystem1 connected to the battery is a current controlled inverter (CCI). It is three phase and bi directional in nature. The P_{REF} signal decides its mode of operation (negative leads to discharge of battery i.e. battery supplies power and positive signal leads to charging of battery) [12],[13]. The SM is rated at 300KVA and the inertia constant is 1s. The clutch enables to lock or disengage the voltage regulator (IEEE type 1) plus the exciter. The clutch block is shown in Fig. 2.3. When the input CLUTCH is 0 transmitted torque is 0 and when it is 1 the DE and SM behave as coupled and the transmitted torques is given as:

$$T_C = \frac{H_S T_d + H_d T_S}{H_S + H_d} \tag{2.1}$$

Where H_S(=1s) and H_d(=0.75s) are inertia constants of SM and DE and T_d and T_S are torques of DE and SM respectively. The speed regulator and actuator, which are the components of DE is inside the diesel engine block and is shown in Fig. 2.4.

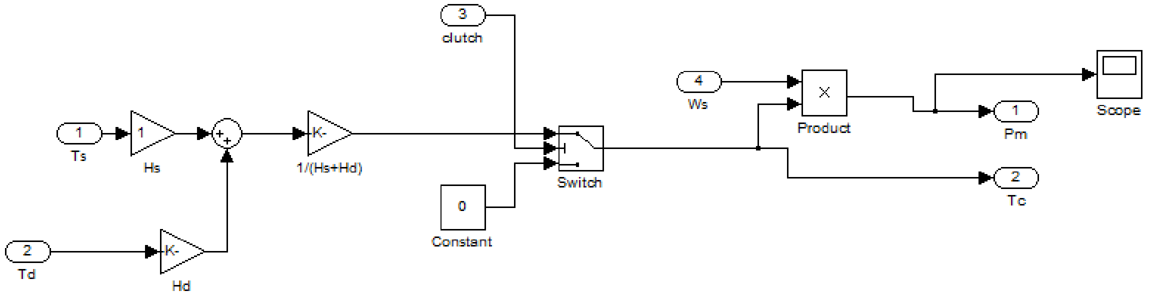


Fig.2.3. Simulink schematic of clutch.

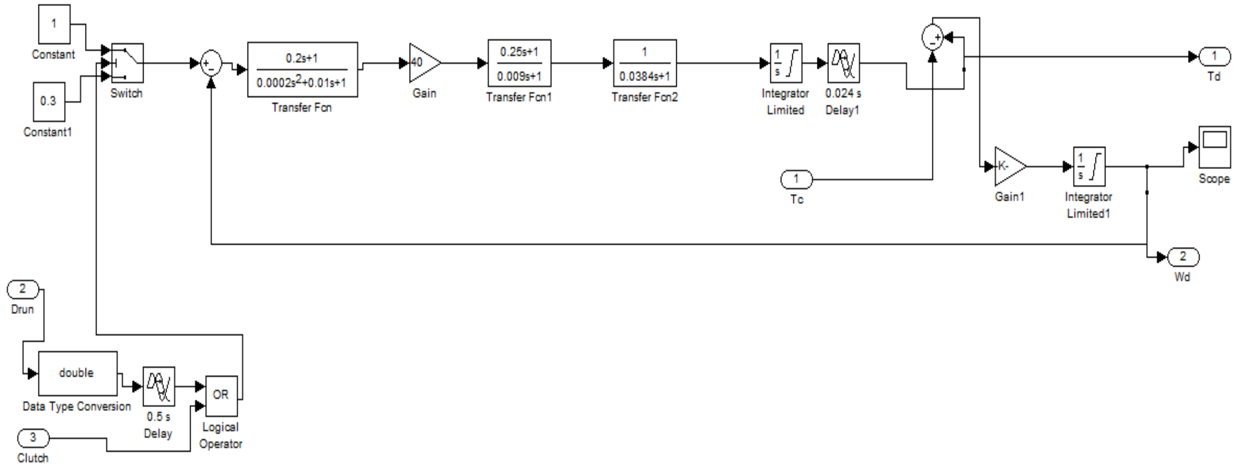


Fig.2.4. Simulink model of DE, actuator and speed regulator.

For WO the reference speed of DE is 0.3 pu (runs at low speed) as it simplifies the simulation of the DE cranking process. In this thesis with respect to standard values the firing speed is 0.3s and cranking time of 0.5s. The truth table for the transition is shown in table 2.2.

TABLE 2.2

Transition truth table

Signal Drun	Signal Clutch	Speed Ref. of DE (pu)	State of WDHS
0	0	0.3	WO
1	0	1	Shift from WO to WD
0	1	1	Shift from WD to WO
1	1	1	WD

The mains failure detector helps to monitor the WO mode. Whenever the frequency doesn't sustain due to active power shortage it gives an output signal of 1 indicating a need to change in mode of operation. The most vital part of the model is the active power regulator (APR) whose model is shown in Fig. 2.5.

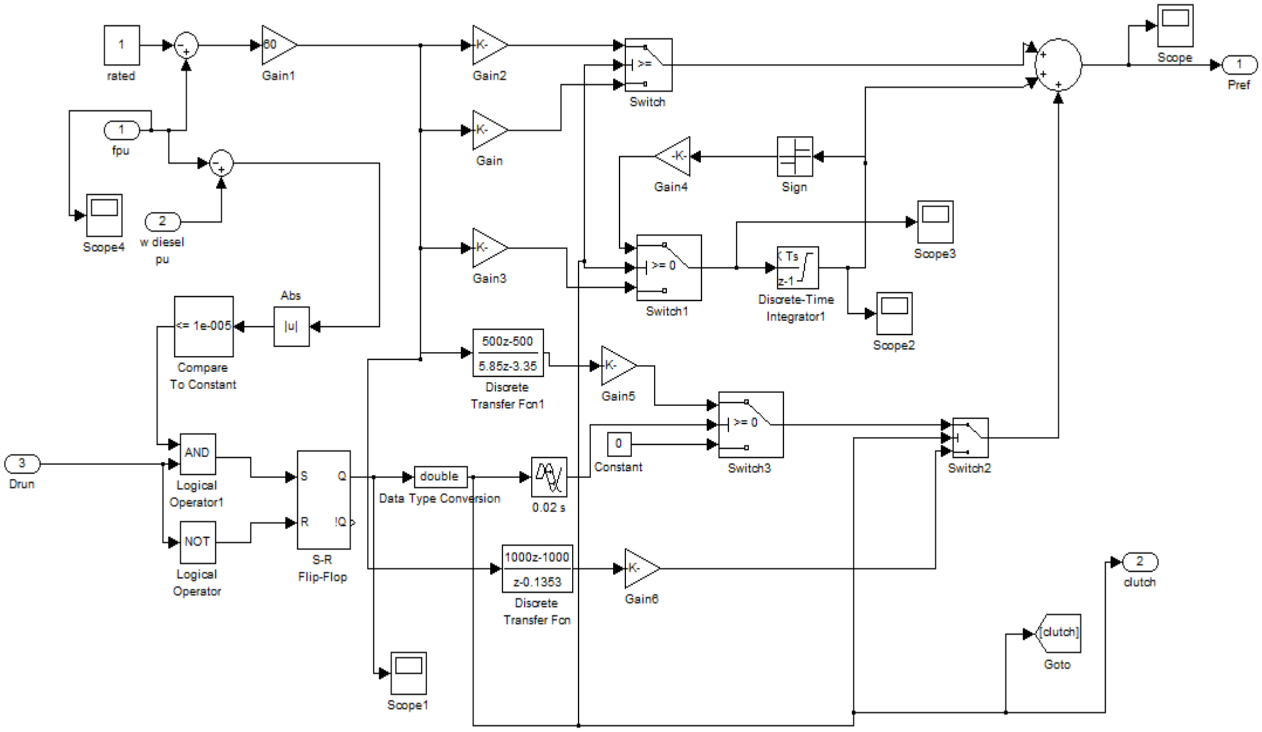


Fig.2.5. APR schematic.

CLUTCH, the output from APR selects between PID control (for WO mode) and PD control (for WD mode). The values of the gain constants have been taken from ref. [13]. They have been taken so that the dominant pole pair becomes a double pole which helps to alleviate the speed response and reduce under/over shooting. It is also observed that a lead compensator has been used in place of a pure derivative block. The 0.00001 pu speed constraint aids for an easier clutch model and hence the engaged state need not be modelled. The P_{REF} output goes to CCI which then controls the battery system as described previously.

2.5 SIMULATION RESULTS

To verify the above proposed control strategy the APR simulation was performed. The main load is assumed to consume 100KW. Under this condition the energy produced by the WTG is sufficient to meet the load demand and hence system operates in WO mode. At t=0.1s the three phase breaker is switched on adding an additional 200KW of consumer load. Now this amount of wind energy is not available and hence now the APR sends a signal via clutch to turn on the SM and DE unit to meet the energy demand, thus operating in WD mode. The frequency variation is shown below:

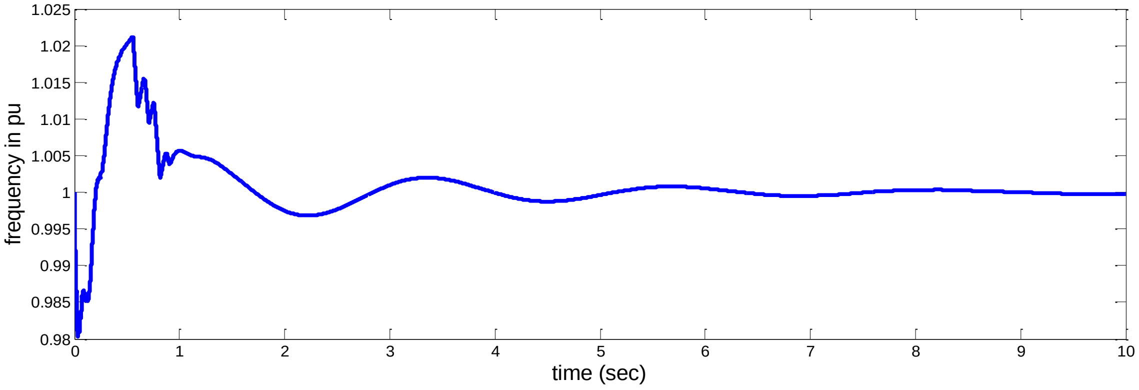


Fig.2.6. WDHS frequency variation in per unit.

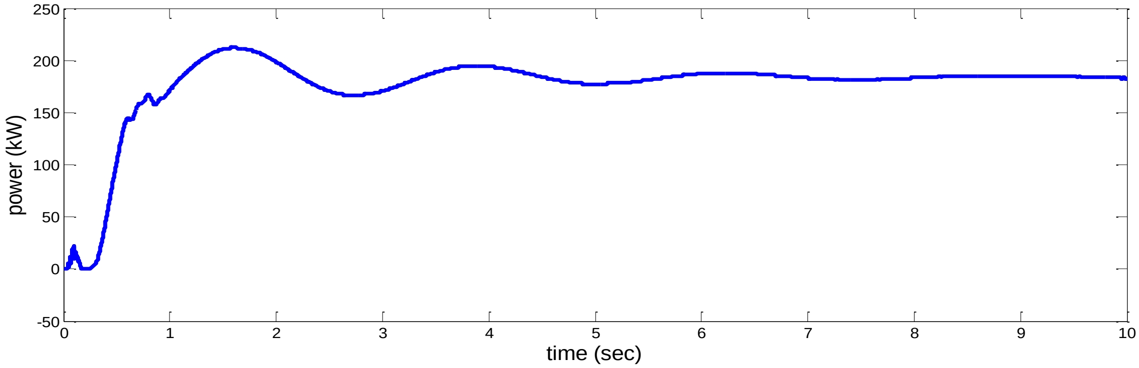


Fig.2.7. Dump load consumption.

The active power generated by the wind turbine for a wind velocity of 10m/s is 220 kW while the synchronous machine produces 250 kW. The total consumption of the load is 300 kW after both the loads are switched on. The rest power is dumped at the dump load and hence the stable state power in Fig. 2.7. is 170 kW. In Fig. 2.6. when at 0.1s the extra load is turned on the frequency dips and soon after the SM comes into picture after one overshoot the frequency gets settled to 1 pu by the APR and hence showing the smooth transition. Had the APR failed the frequency would have gone down. The BESS helps in the smoothing the transition.

2.6 CONCLUSION

The simulation results showed a smooth change from WO to WD mode when the load demand increased. The control strategy was successful as frequency was maintained at 1p.u. The graphs show BESS first moderates the frequency dip and later smoothens the system response. The settling time is also good. Hence the modelling is viable for a practical WDHS.

CHAPTER 3

Dynamic stability performance in WDHS using IG and PMIG: a comparison

3.1 INTRODUCTION

In the previous chapter the simulation was studied using an IG for the WTG. IGs are beneficial as synchronization is not necessary for varying wind speeds. But the IG has poor voltage regulation, power factor and efficiency because it requires magnetizing current [14], [15]. Since PMIG have permanent magnets (mounted on a second rotor) the above shortcomings become better by the use of them. The efficiency is high over a wide range of slip for PMIG. So in this chapter we study the dynamic performance for two different loading conditions while the active and reactive power varies (step change) for both the IG and PMIG case. Many models have been documented in the literature for modelling of PMIG like d-q reference model [16], impedance model [17] etc. STATCOMs are proposed to eliminate the mismatch of reactive power. The STATCOM used in this thesis uses a VSC which internally generates reactive power. The mathematical model is based on small signal model using state space modelling. The nomenclatures used in this chapter are:

K_{E}, K_{F}, K_{A} : gain of exciter, stabilizer and voltage regulator.

$\Delta E_{fd}, \Delta E_{q}$: small deviations in voltage of exciter, and internal armature emf of SG.

$\Delta E_{q}'$: small deviations in internal armature emf of SG in transient condition.

K_{P}, K_{I} : PI gains of STATCOM and converter controllers.

Q_{WG}, P_{WG} : reactive and active power generated by wind generators.

Q_{DG}, P_{DG} : reactive and active power consumed by DGs.

Q_{com} : reactive power supplied by STATCOM.

ΔP_{IW} : small change in input power of wind.

$\Delta\alpha$: phase angle deviation of STATCOM.

$T\alpha, T_d, T_1$: transport lag, average dead time of zero crossing and main time constant.

R_{eq}, X_{eq}, X_m : equivalent resistance, reactance and magnetizing reactance of PMIG/IG.

s : slip

X_d, X_d' : direct axis reactance of SG.

3.2 MATHEMATICAL MODELLING OF THE SYSTEM

The single line diagram of a stand-alone wind-diesel hybrid system is shown in Fig. 3.1. Under stable condition the real and reactive power are balanced as shown below:

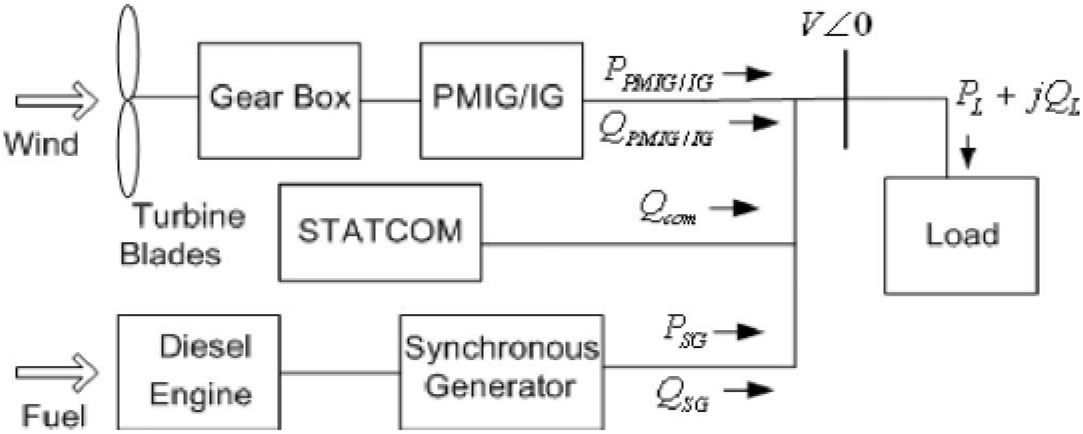


Fig.3.1. System layout.

If there is a change in reactive power of load (ΔQ_L), the voltage of system becomes [18]:

$$\Delta V(s) = \frac{K_V}{1+sT_V}[\Delta Q_{DG}(s) + \Delta Q_{com}(s) + \Delta Q_{WG}(s) - \Delta Q_L(s)] \tag{3.1}$$

where K_V and T_V are system gain and time constant respectively. The composite loads undergo an increase in voltage as they are connected to the system. As in the previous chapter the exciter system is IEEE type 1. With saturation being neglected and using the equations of [19] the model is shown below. The constants used in this thesis are: $K_E = 1$, $K_A = 40$, $K_F = 0.5$, $T_E = 1$sec, $T_A = 0.05$sec, and $T_F = 0.55$sec.

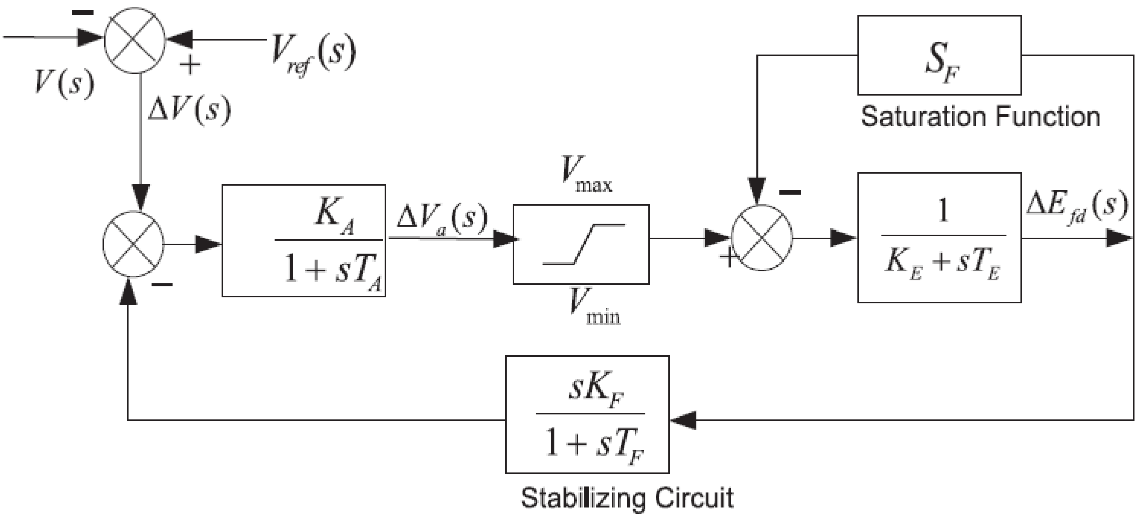


Fig.3.2. S_F assumed to be zero, IEEE type 1 exciter.

For small perturbations voltage behind transient reactance is given as [19]:

$$\Delta E'_q(s) = \frac{1}{1+sT_G}(K_1 \Delta E_{fd}(s) + K_2 \Delta V) \tag{3.2}$$

where $K_1 = X_d'/X_d$, $K_2 = [(X_d'-X_d)\cos\delta]/X_d$ and $T_G = T_{do}'X_d'/X_d$. T_{do}' is the direct axis open circuit transient time constant (here taken as 5sec.).

Further from [19], the change in reactive power of SG is given as:

$$\Delta Q_{DG}(s) = K_3 \Delta E'_q(s) + K_4 \Delta V(s) \tag{3.3}$$

Where $K_3 = V\cos\delta/X_d'$ and $K_4 = [E_q'\cos\delta - 2V]/X_d'$.

The approximate circuit of PMIG is similar to that of IG except the addition of an extra magnetizing reactance in parallel with core loss reactance. From [20], the equations for reactive power consumption of PMIG can be given as:

$$\Delta Q_{PMIG} = K_5 \Delta V(s) \tag{3.4}$$

where

$$K_5 = \frac{-2X_{eq}V}{R_Y^2+X_{eq}^2} + \frac{V^2}{X_C}\left\{\frac{3aV^2+2bV+c}{3X_C^3} - \frac{2}{V}\right\} \tag{3.5}$$

$$R_Y = R_P + R_{eq} \tag{3.6}$$

$$R_P = \frac{r_2'}{s}(1-s) \tag{3.7}$$

$$X_C = (aV^3 + bV^2 + cV + d)^{\frac{1}{3}} \tag{3.8}$$

$$X_{eq} = x_1 + x_2' \tag{3.9}$$

$$R_{eq} = r_1 + r_2' \tag{3.10}$$

However if the input wind power also changes the above equations modifies into the following:

$$\Delta Q_{PMIG} = K_6 \Delta P_{IW}(s) + K_7 \Delta V(s) \tag{3.11}$$

Where

$$K_6 = \frac{-2X_{eq}R_Y V^2}{R_Y^2+X_{eq}^2\{2R_Y(P_{IW}-P_{coreloss})+V^2\}} \tag{3.12}$$

$$K_7 = \left[K_{C1} + \frac{V^2}{X_C}\left\{\frac{(3aV^2+2bV+c)}{(3X_C^3)} - \frac{2}{V}\right\}\right] \tag{3.13}$$

For the above equations if X_C is infinite then the PMIG behaves as IG. In this chapter a STATCOM is used for meeting the needs of reactive power. It is shunt connected and their characteristics are similar to that of synchronous condenser without mechanical inertia as they use solid state devices which have fast operations. It consists of a coupling transformer, a DC capacitor and VSI. The reactive power exchange is produced by voltage difference across leakage reactance such that the voltage profile of the system is maintained. A schematic model is shown in Fig. 3.3.

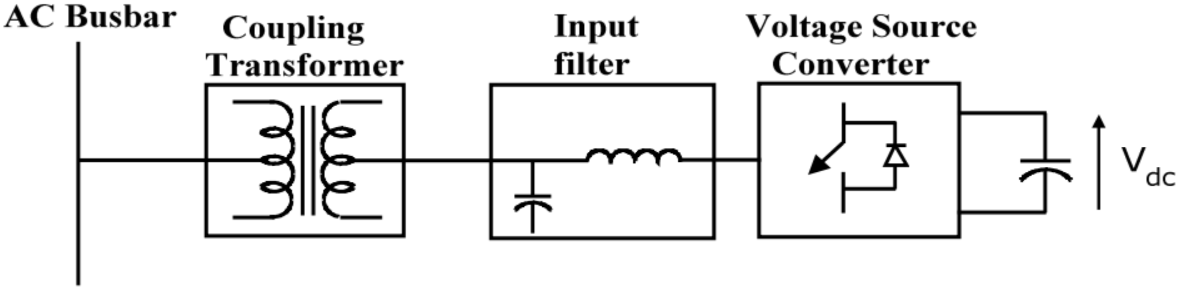


Fig.3.3. STATCOM Schematic.

In this thesis the real part of current of the STATCOM is taken to be zero. Here the control is done by the control of the phase angle of the system bus voltage and by control of α. The reactive power contributed by the STATCOM is given as [21]:

$$Q_{com} = kV_{dc}^2B - kV_{dc}VB\cos(\alpha - \delta) + kV_{dc}VG\sin(\alpha - \delta) \tag{3.14}$$

Where G and B are line parameters. As the bus voltage is taken as reference, δ is taken as zero. Further the admittance is assumed to be zero. So upon linearizing the equation becomes:

$$\Delta Q_{com} = K_8\Delta\alpha(s) + K_9\Delta V(s) \tag{3.15}$$

Where $K_8 = kV_{dc}B\sin\alpha$ and $K_9 = -kV_{dc}B\cos\alpha$. 'k' is the inverter's pulse number with modulation index as unity. The simulation model is shown in Fig. 3.4. The STATCOM small signal model is shown in Fig.3.5.

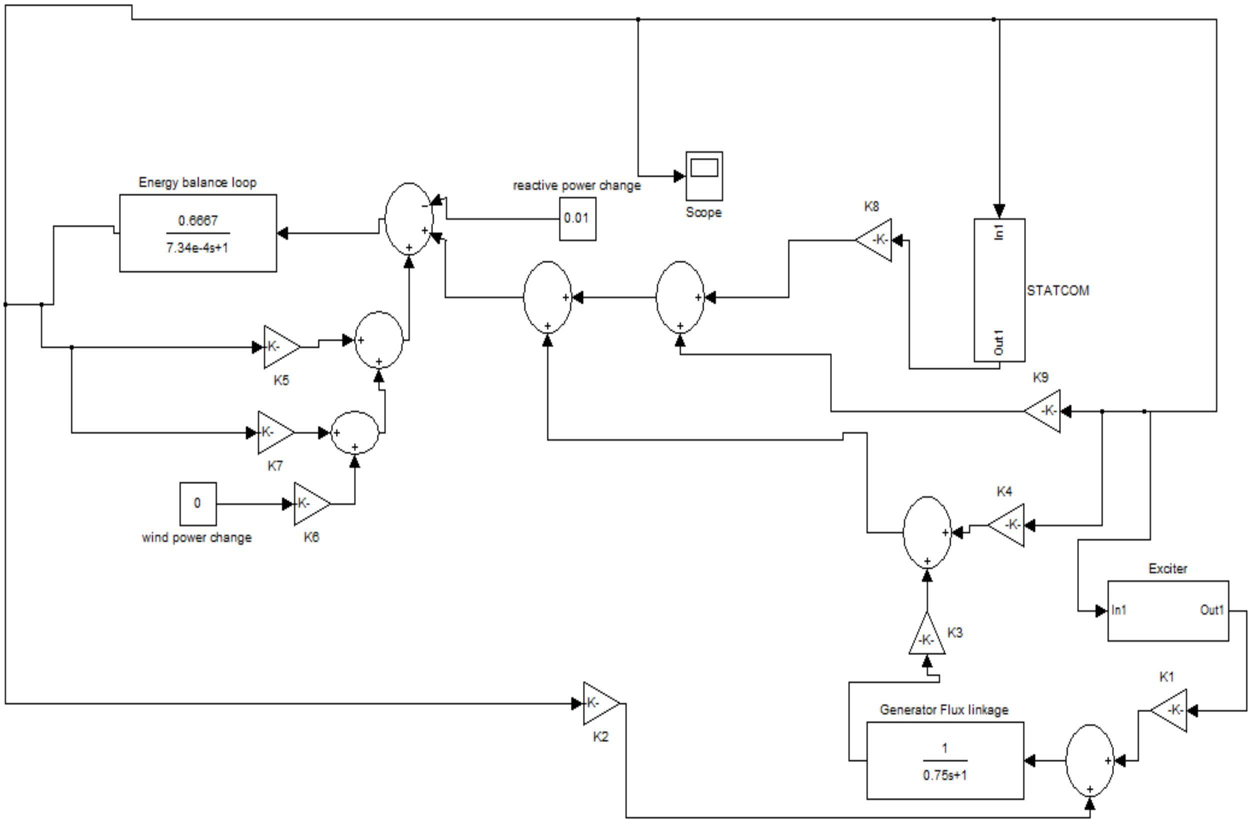


Fig.3.4. Transfer function block diagram.

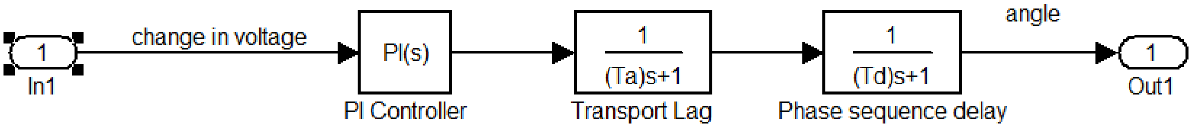


Fig.3.5. Small signal model of used STATCOM

3.3 SIMULATION AND TRANSIENT PERFORMANCE

Performance investigation is done for both IG and PMIG case by considering two examples (two different loading case) of WDHS i.e. W-D1 and W-D2. The values of parameters are given in table 3.1. Using the ISE criterion the optimal gain of the PI constants are decided for the STATCOM. The gain values needed for optimization are higher when the size of STATCOM decreases which occurs when the amount of wind power generated by WTG decreases.

TABLE 3.1

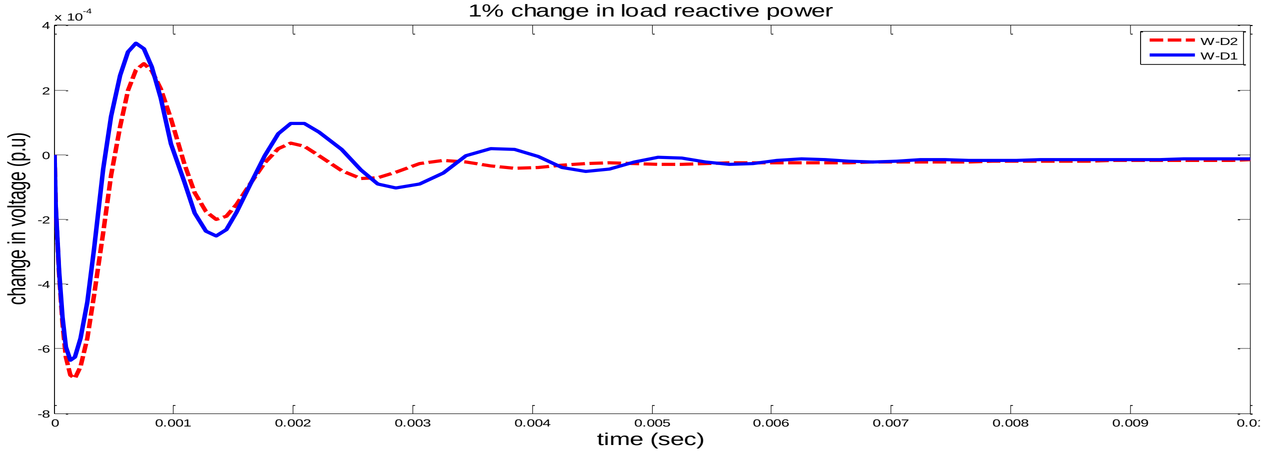
Value of parameters of W-D1 and W-D2

System Parameter	W-D1	W-D2
Capacity of WG (kW)	1200	600
Capacity of DG (kW)	1500	1500
Load consumption (kW)	2500	1500
Base power (kVA)	2500	1500
SG (all in p.u)		
P_{SG}	0.5	0.67
Q_{SG}	0.15	0.33
E_q	1.12	1.1
E_q'	0.96	0.81
δ (degree)	20	35
X_d'	0.15	0.15
X_d	1	1
IG (all in p.u)		

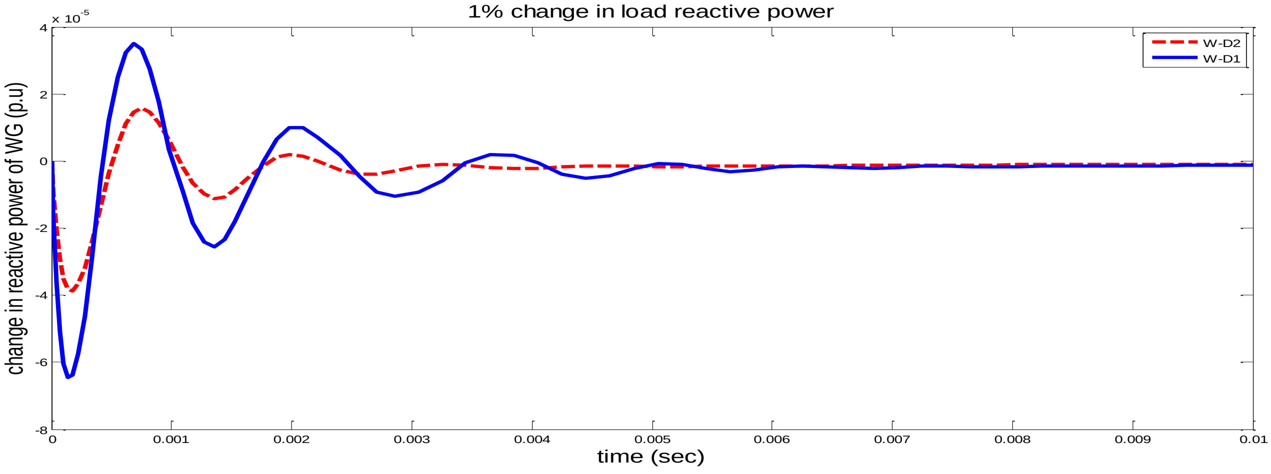
P_{IG}	0.5	0.33
Q_{IG}	0.21	0.16
$r_1 = r_2'$	0.15	0.25
$x_1 = x_2'$	0.5	0.75
s (%)	-3	-3
PMIG (all in p.u)		
P_{IG}	0.5	0.33
Q_{IG}	0.21	0.16
$r_1 = r_2'$	0.15	0.25
$x_1 = x_2'$	0.5	0.75
s (%)	-3	-3

The loading of diesel generator is 66.67% under regular operating conditions whereas the efficiency of the IG and PMIG is 90%. The STATCOM constants are: main time constant is 20ms, delay time constant (T_d) is 1.67ms and transport lag time constant (T_α) is 0.25ms. The load is assumed to operate at 0.8 power factor. Hence using the above table the constants K1-K9 can be calculated. K_V is taken as 0.667 while T_V = 7.34E-04 sec.

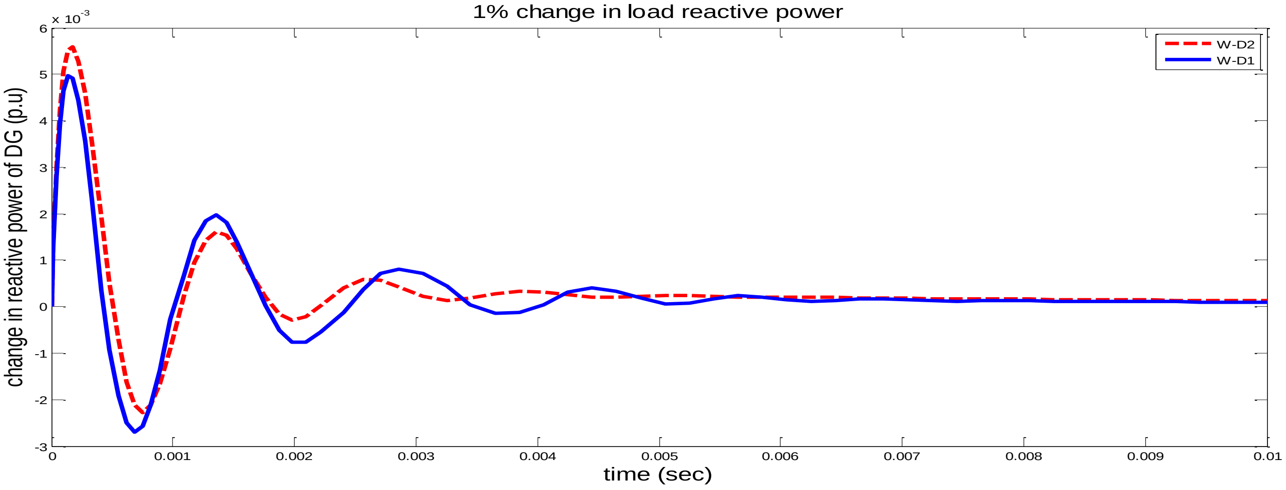
To observe the transient performance the change in system voltage and the reactive power of the STATCOM, diesel engine and that of the WTG (either IG or PMIG) are observed. The same is done by first observing a change with 0.01 (p.u) step change in reactive power of load and then same change in both input wind power and load reactive power. Fig. 3.6 shows the graphs of IG for both the examples and perturbation of load power while Fig. 3.7 shows that of both load and wind power. Similarly Fig. 3.8 and Fig. 3.9 show the results of PMIG.


1% change in load reactive power
x 10^-4
4
2
0
-2
-4
-6
-8
change in voltage (p.u)
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
time (sec)
W-D2
W-D1

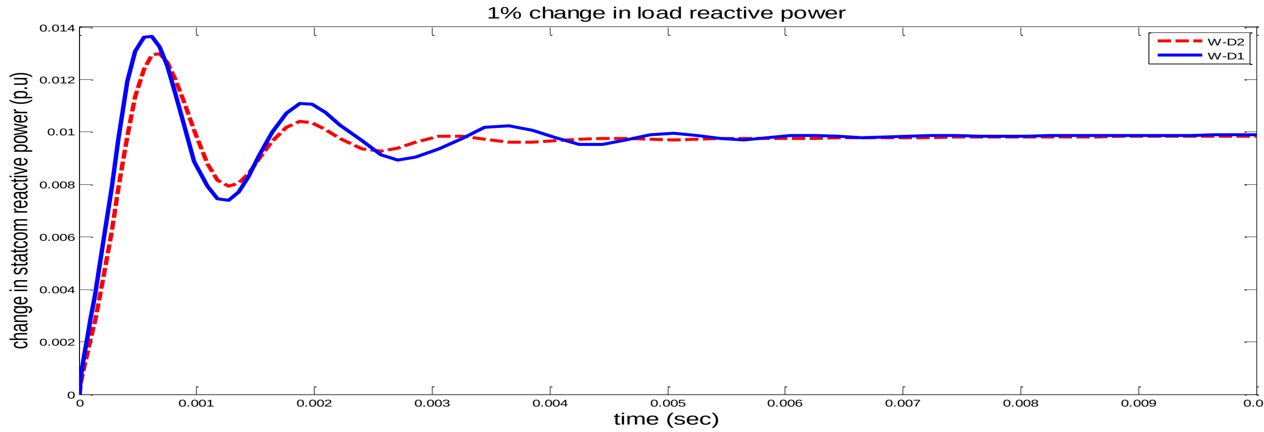
(a)


1% change in load reactive power
x 10^-5
4
2
0
-2
-4
-6
-8
change in reactive power of WG (p.u)
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
time (sec)
W-D2
W-D1

(b)

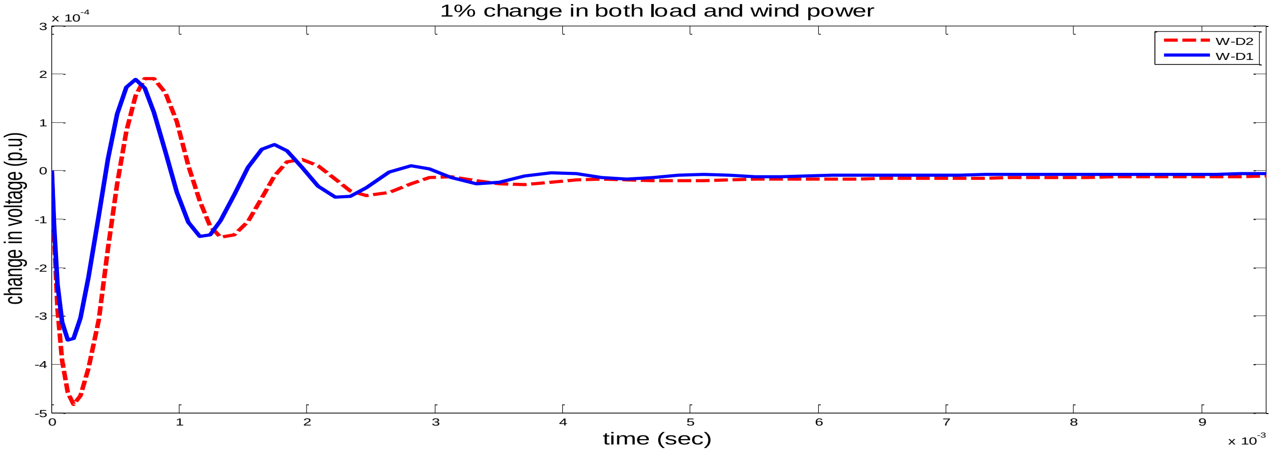

1% change in load reactive power
x 10^-3
6
5
4
3
2
1
0
-1
-2
-3
change in reactive power of DG (p.u)
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
time (sec)
W-D2
W-D1

(c)

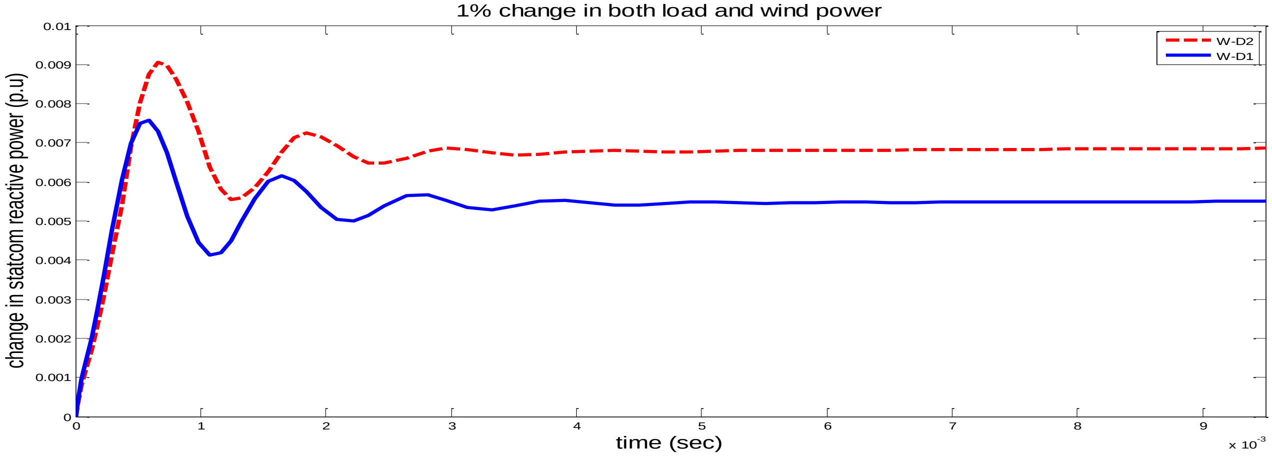


(d)

Fig.3.6. Variation in (a) voltage (b) WG power (c) DG power (d) STATCOM power for 0.01 (p.u) step change in load reactive power for IG.

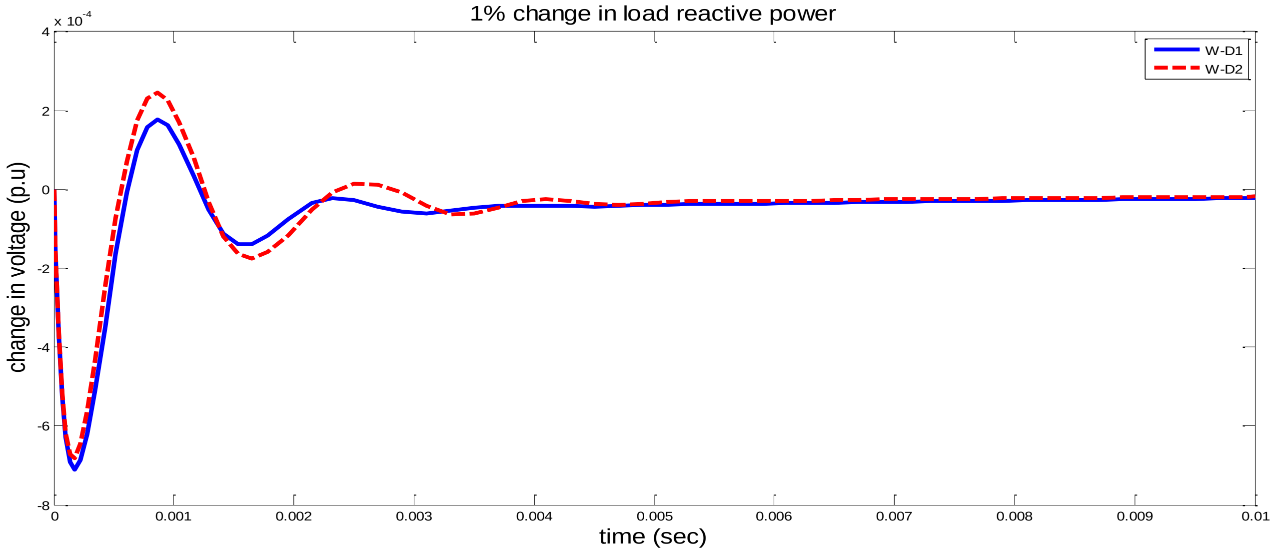


(a)

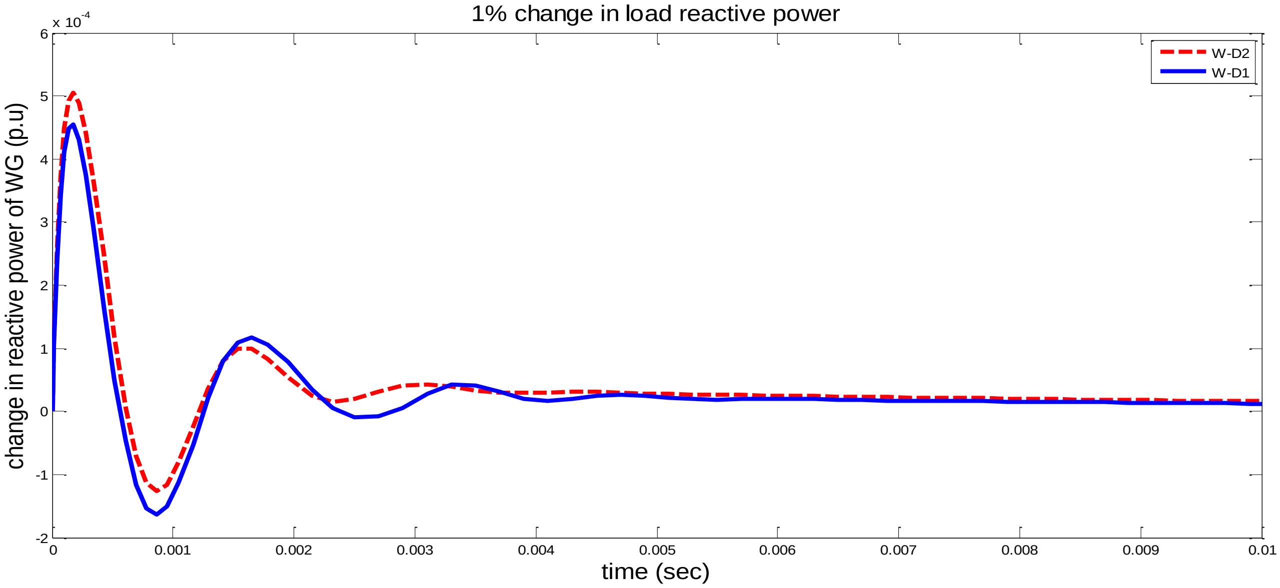


(b)

Fig.3.7 Variation in (a) voltage (b) STATCOM power for 0.01(p.u) step change in both load and wind power for IG.


1% change in load reactive power
x 10^-4
4
2
0
-2
-4
-6
-8
change in voltage (p.u)
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
time (sec)
W-D1
W-D2

(a)


1% change in load reactive power
x 10^-4
6
5
4
3
2
1
0
-1
-2
change in reactive power of WG (p.u)
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
time (sec)
W-D2
W-D1

(b)

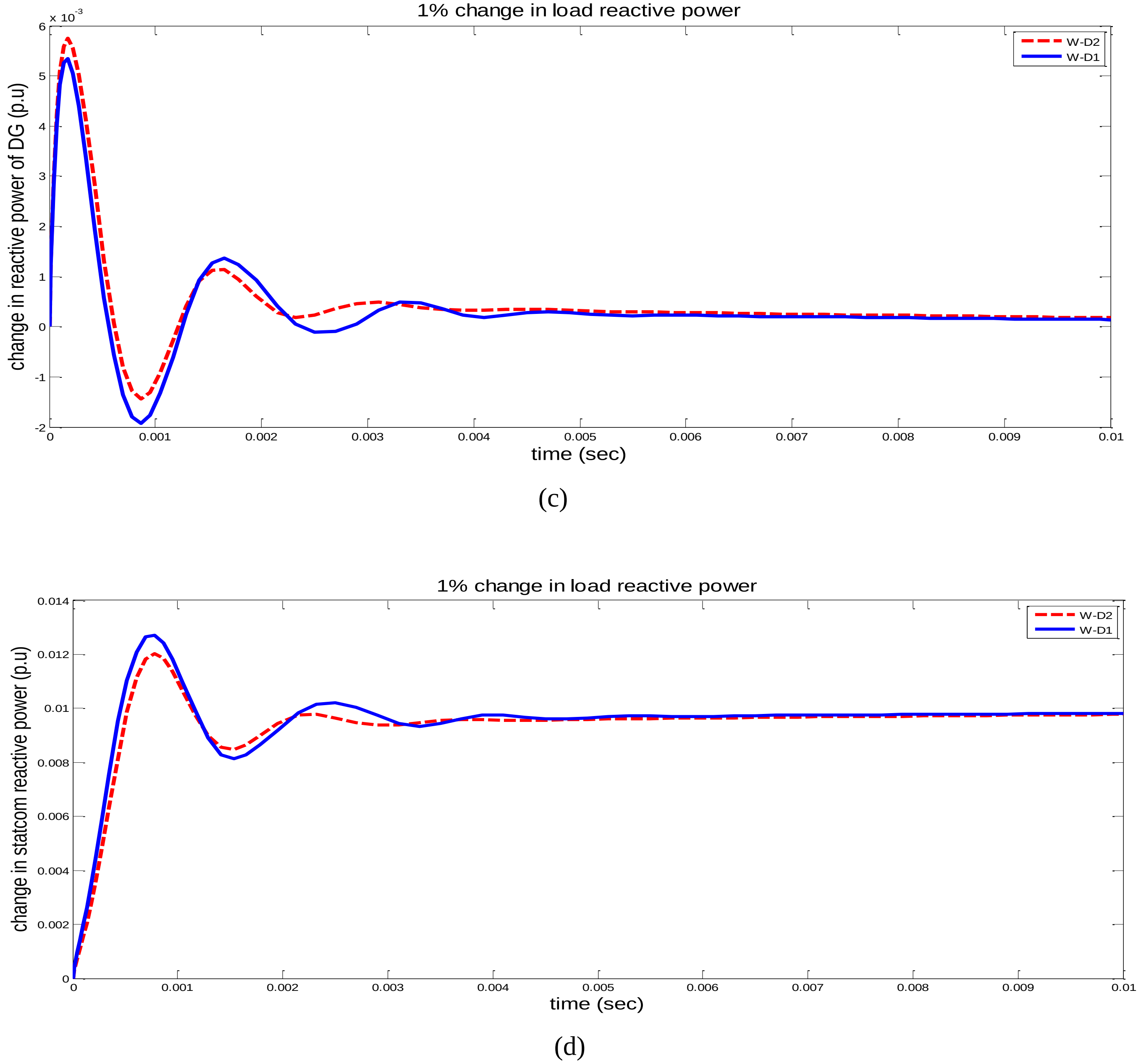
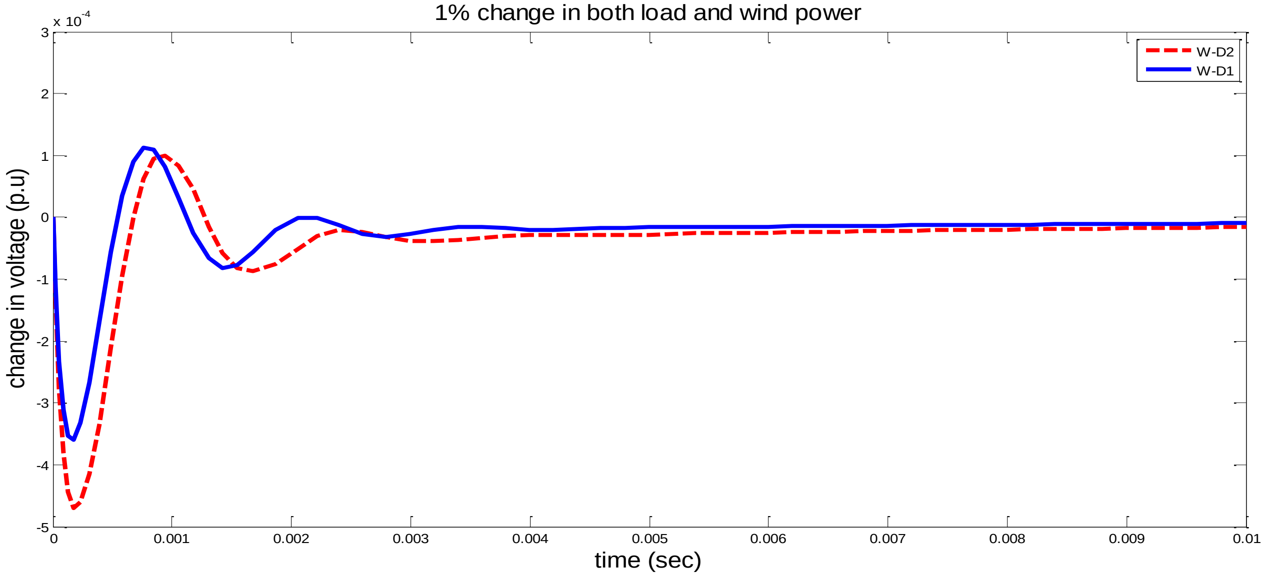
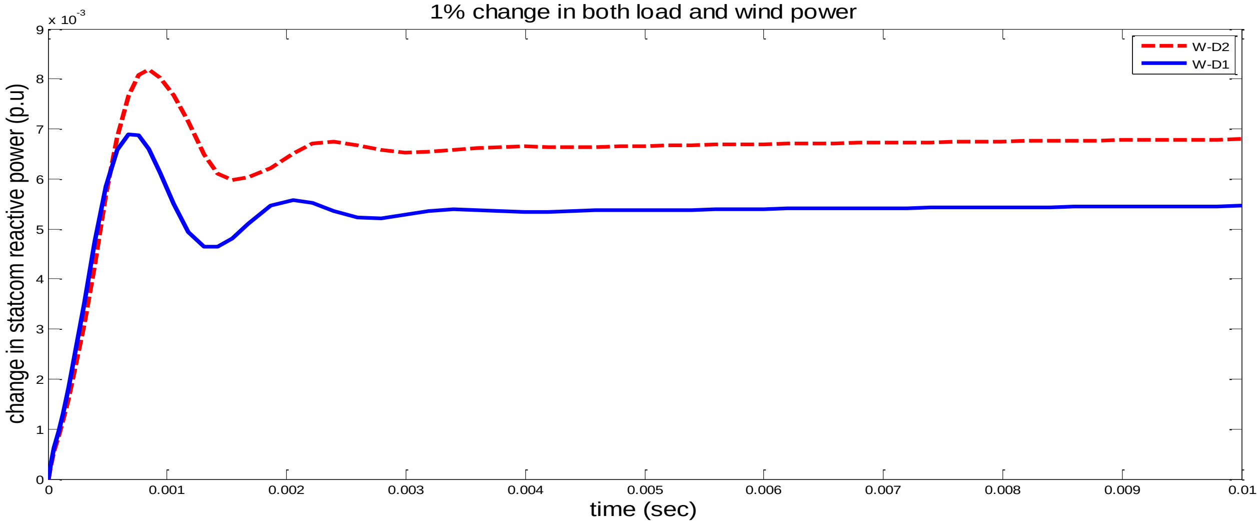


Fig.3.8 (a) change in voltage (b) change in WG power (c)change in DG power and (d) change in STATCOM power for 0.01 (p.u) step change in load reactive power for PMIG.



(a)



(b)

Fig.3.9. (a) change in voltage (b) change in STATCOM power for 0.01 (p.u) step change in both load reactive and wind power for PMIG.

From the results it is seen that the peak voltage deviation is more for the wind turbine with larger capacity (W-D1), for IG as is evident form Fig.3.6 (a). But the same is less for PMIG as is evident from Fig.3.8 (a). It is also observed that the STATCOM immediately supplies the extra reactive power of 0.01 p.u as is evident from Fig. 3.6 (d) and Fig. 3.8 (d). After stabilization it is the STATCOM that caters the deficit reactive power demand. The STATCOM has a very fast response as seen from the graphs, where steady state is achieved within 0.01sec. As seen from Fig. 3.7 and Fig. 3.9 the reactive power demand increases when there is step increase in both load and wind power. The automatic voltage regulators used with the diesel engines are not able to maintain the voltage as desired and hence the above setup with STATCOM helps to achieve the system constraint.

3.4 CONCLUSION

Two examples of WDHS were considered for study with different wind generation capacity and the response was compared with IG and PMIG. It is shown how the STATCOM serves the purpose for fast action to maintain the stability. PMIG have definitely the edge over IG as use for WTG. The size of STATCOM also reduces when PMIG is used; however they have comparable fluctuations when the WDHS system uses IG. The agreement with the simulation results to a prodigious extent that use of PMIG can definitely be beneficial.

CHAPTER 4

CONCLUSION AND FUTURE WORK

4.1 CONCLUSIONS

Here, in the thesis a stand-alone WDHS was successfully modelled which have become a crucial part for communities that are far away from utility grid.

- A control strategy was developed for the WDHS such that there was a smooth transition from WO mode to WD mode when there was power shortage.
- An IG was used to model the above design with no pitch control. An assumption for sake of simplicity was done while designing the clutch system. The DE instead of being completely stopped was allowed to run at a slow speed.
- A BESS system was also introduced in the WDHS such that the transition was smooth.
- After considering the previous system next a mathematical model was developed for investigating the performance of IG and PMIG under dynamic conditions.
- Simulation results were then obtained to show that PMIG can definitely be a better bargain as compared to IG.

4.2 FUTURE WORK

- In chapter 2 we used a PD controller. Better results can be expected by use of fuzzy logic for control strategy.
- Apart from PMIG performance for permanent magnet synchronous generator (PMSG) can also be studied to get an overall idea about which generator would serve the purpose for energy production to the best along with use of artificial neural nets.

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