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A new real time approach using dSPACE R&D Controller Board for reactive power control by SVC in autonomous wind-diesel hybrid power systems

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Abstract

This paper presents the reactive power control of Autonomous Wind-Diesel Hybrid Power Systems (AWDHPS) under dSPACE real time environment. The reactive power absorption and supply is done by a Static VAR Compensator (SVC) controlled by proportional plus integral controller and tuned by dSPACE DS 1104. Three models of AWDHPS are considered in the study. The disturbance parameters in the models were the change in reactive power of the load (ΔQ_L), the change in mechanical power input of the induction generator (ΔP_{IW}) and the change in mechanical power input of two induction generators (ΔP_{IW1}, ΔP_{IW2}) respectively. The parameters were dynamically varied in control desk of dSPACE Software with DS1104 Research and Development controller board mounted in personal computer under real time environment.

Keywords: autonomous wind-diesel hybrid power system, dSPACE, induction generator, synchronous generator, static var compensator.

1. Introduction

Wind energy has gained a large momentum during the past two decades. The total installed wind capacity of the world reached 159 GW in 2009. India ranks fifth in the world with an installed capacity of around 10 GW (World Wind Energy Report, 2009). In the Sagar Island, West Bengal of India a wind-diesel system comprising of 200 kW wind power and 280 kW diesel generator set is providing electricity to the villages in that island (Auroville Wind Systems, 2010). Autonomous power systems produce electricity near the location of use and restrict grid expansion. The integration of wind energy system into the existing autonomous power system leads to a wind energy based autonomous hybrid power system (Sivachandran et al., 2007). The AWDHPS is becoming a viable and cost effective approach for remotely located communities (Elhadidy and Shaahid, 2005). In AWDHPS the wind energy system is the main constituent and diesel system forms the back up. This type of hybrid power system saves fuel cost, improves power capacity to meet the increasing demand and maintains the continuity of supply in the system (Bansal et al., 2005).

The reactive power control of AWDHPS is based on the mathematical modeling of the system using power equations. The components of AWDHPS such as induction generator, synchronous generator, IEEE type – I excitation system and SVC are modeled individually to achieve their transfer functions. Then these transfer function blocks are combined together to build the MATLAB / Simulink model of the AWDHPS (Bansal, 2006). The SVCs are used to control the reactive power (Dixon et al., 2005; Hingorani, 2000). The MATLAB / Simulink models of the AWDHPS were developed to perform the reactive power control under constant speed, variable speed and multi-wind diesel operations (Bansal et al., 2004; Bansal and Bhatti, 2007).

Real time study is performed with state of the art tools and real time digital simulators such as dSPACE, OPAL-RT and RTDS. The system modeling, simulation, real-time digital signal processing, and control are performed in an integrated laboratory. Here a

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common visual programming interface links the software simulation and testing of actual systems (Kozick and Crane, 1996). A 11 KW variable speed wind turbine control model is developed using MATLAB / Simulink and tested with dSPACE DS 1103 (Mihet-Popa et al., 2008). OPAL-RT lab was used as hardware in the loop real-time control system platform in solar panels operated with single-phase 11-level cascade multilevel DC-AC grid-connected inverter (Filho et al., 2010). A novel real-time simulation was performed for photovoltaic generation systems under real weather conditions using a real-time digital simulator (RTDS) (Park and Yu, 2004).

This paper presents the reactive power control of Autonomous Wind-Diesel Hybrid Power Systems (AWDHPS) using dSPACE DS 1104. The reactive power absorption and supply is done by a Static VAR Compensator (SVC) controlled by proportional plus integral controller and tuned by dSPACE DS 1104.The MATLAB / simulink block diagrams of AWDHPS were built in dSPACE real time environment. The reactive power control simulation was performed for three models of AWDHPS. The disturbance parameters in the models were the change in reactive power of the load (ΔQ_L), the change in mechanical power input of the induction generator (ΔP_{IW}) and the change in mechanical power input of two induction generators (ΔP_{IW1}, ΔP_{IW2}) respectively. The parameters were dynamically varied in control desk of dSPACE Software with DS1104 Research and Development (R & D) controller board mounted in personal computer under real time environment. The static and dynamic response curves were depicted and the time domain response specifications were tabulated.

2. Autonomous wind-diesel hybrid power system

The block diagram of the AWDHPS is shown in figure 1. A Synchronous Generator (SG) with IEEE type-I excitation system connected on the diesel system and the Induction Generator (IG) connected on the wind energy-conversion system together forms the hybrid power system. The reactive power absorption and supply is done by a proportional plus integral Static VAR Compensator.

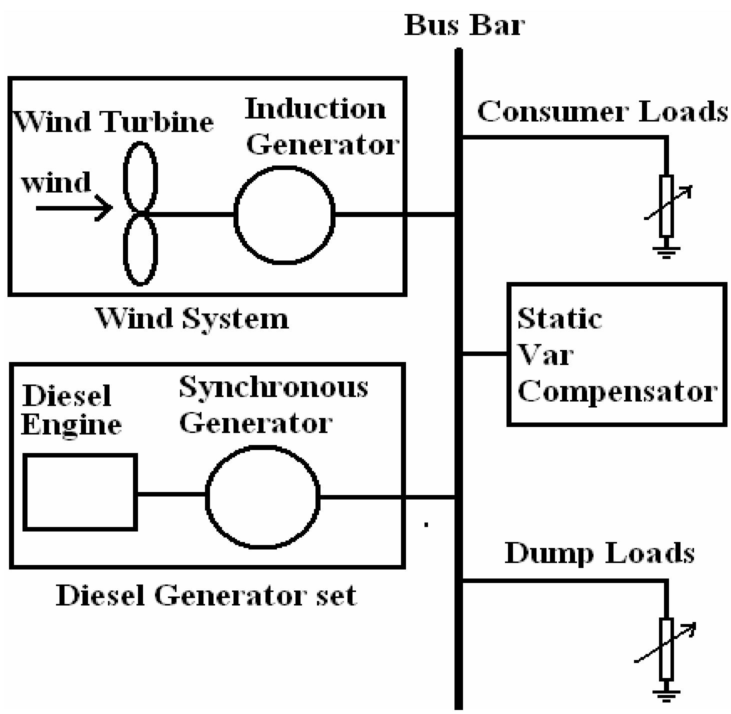


Figure 1. Block diagram of Autonomous Wind-Diesel Hybrid Power System

The AWDHPS has been classified into three models based on the disturbance variables of the system as shown in figure 2.

(i) AWDHPS Model – I: It is a Static Response Model (one variable). It is subjected to variation of change in reactive power of the load (ΔQ_L) alone.

(ii) AWDHPS Model – II: It is a Dynamic Response Model (two variables). It is subjected to variation of both ΔQ_L and change in mechanical power input of the induction generator (ΔP_{IW}).

(iii) AWDHPS Model – III: It is a Dynamic Response Model (three variables). It has two wind system and one diesel system. It is subjected to variation of ΔQ_L and change in mechanical power input of two induction generators (ΔP_{IW1}, ΔP_{IW2}).

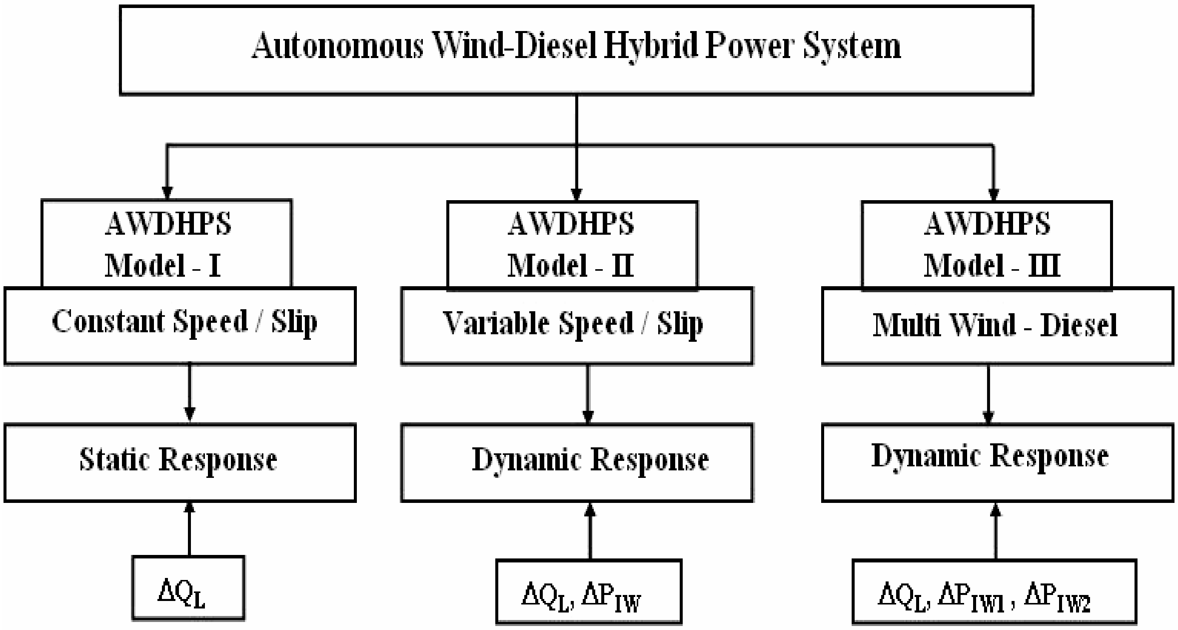


Figure 2. Classification of AWDHPS based on number of disturbance variables

The equations governing the reactive power control of AWDHPS are given below (Bansal et al., 2004). The change in system voltage due to reactive power disturbances of the AWDHPS is given by

$$\Delta V(s) = \frac{K_V}{1 + sT_V}\left[\Delta Q_{SG}(s) + \Delta Q_{SVC}(s) - \Delta Q_L(s) - \Delta Q_{IG}(s)\right] \tag{1}$$

where

ΔQ_{SG}	=	change in reactive power generated by SG (pu kVAR);
ΔQ_{SVC}	=	change in reactive power generated by SVC (pu kVAR);
ΔQ_L	=	change in reactive-power-load demand (pu kVAR);
ΔQ_{IG}	=	change in reactive power required by IG (pu kVAR);
K_V	=	AWDHPS gain constant;
T_V	=	AWDHPS time constant in seconds.

The change in reactive power of the synchronous generator, induction generator and SVC are given by the equations (2), (3) and (4) respectively (Bansal et al., 2004).

$$\Delta Q_{SG}(s) = K_3 \Delta E'_q(s) + K_4 \Delta V(s) \tag{2}$$

$$\Delta Q_{IG}(s) = K_7 \Delta V(s) + K_6 \Delta P_{IW}(s) \tag{3}$$

$$\Delta Q_{SVC}(s) = K_8 \Delta V(s) + K_9 \Delta B_{SVC}(s) \tag{4}$$

where

ΔB_{SVC}	=	change in reactive susceptance of SVC;
$\Delta E'_q$	=	change in internal armature emf under transient conditions of SG.

The simulink model of AWDHPS - III is shown in figure 3. The three simulink models of AWDHPS were simulated in the MATLAB environment and the performance was studied. The simulation was carried out using the AWDHPS data – I for AWDHPS Model – I and AWDHPS Model - II. The AWDHPS data – II was used for AWDHPS Model - III. The AWDHPS data – I and II are given in the Appendix. The disturbance parameters (ΔQ_L, ΔP_{IW}, ΔP_{IW1} and ΔP_{IW2}) are dynamically varied in control desk of dSPACE Software with DS1104 R & D controller board mounted in personal computer under real time environment.

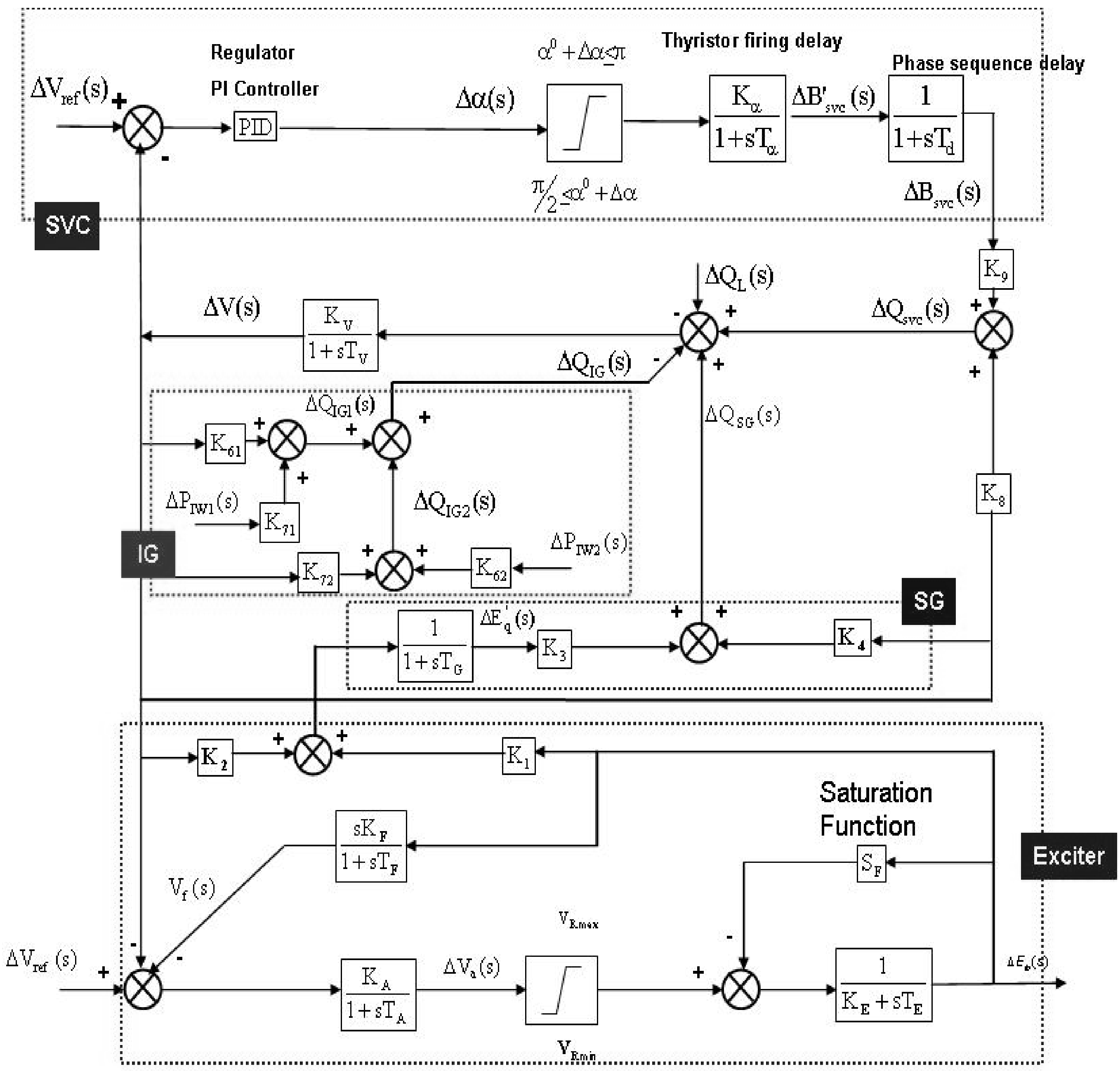


Figure 3. Simulink Model of AWDHPS Model – III

3. dSPACE simulation of AWDHPS

The dSPACE system consists of three components: the DS1104 controller board mounted within a personal computer, a breakout panel for connecting signal lines to the DS 1104 controller board and software tools for operating the DS1104 controller board through the Simulink environment (dSPACE 2010; Venkatesh and Balamurugan, 2010). The Real Time Interface data of AWDHPS Model - III is shown in figure 4. The figure 5 shows a block diagram of the DS 1104 controller board.

The step by step procedure of dSPACE simulation of AWDHPS is given below:

1. Start Matlab and Simulink.
2. Prepare the AWDHPS model in Simulink as shown in figure 3.
3. Start Control Desk Software.
4. Build the Simulink model. During the build process Matlab converts Simulink model into system description file (sdf) and stores on the DS 1104 Processor.
5. After the building process sdf file is transferred to control desk environment automatically. This file contains information of variables used in simulink model. These variables can be directly plotted using control desk software environment.
6. Start new layout file in control desk and select capture setting block from instrument panel and draw on the layout screen. Similarly select a plotter array and draw it on layout. Select an appropriate variable from down menu and drop into the plotter block.
7. Start animation mode and observe the variation of variables on the plotter array.
8. To save the information use save button on capture setting window and give the name of mat file.

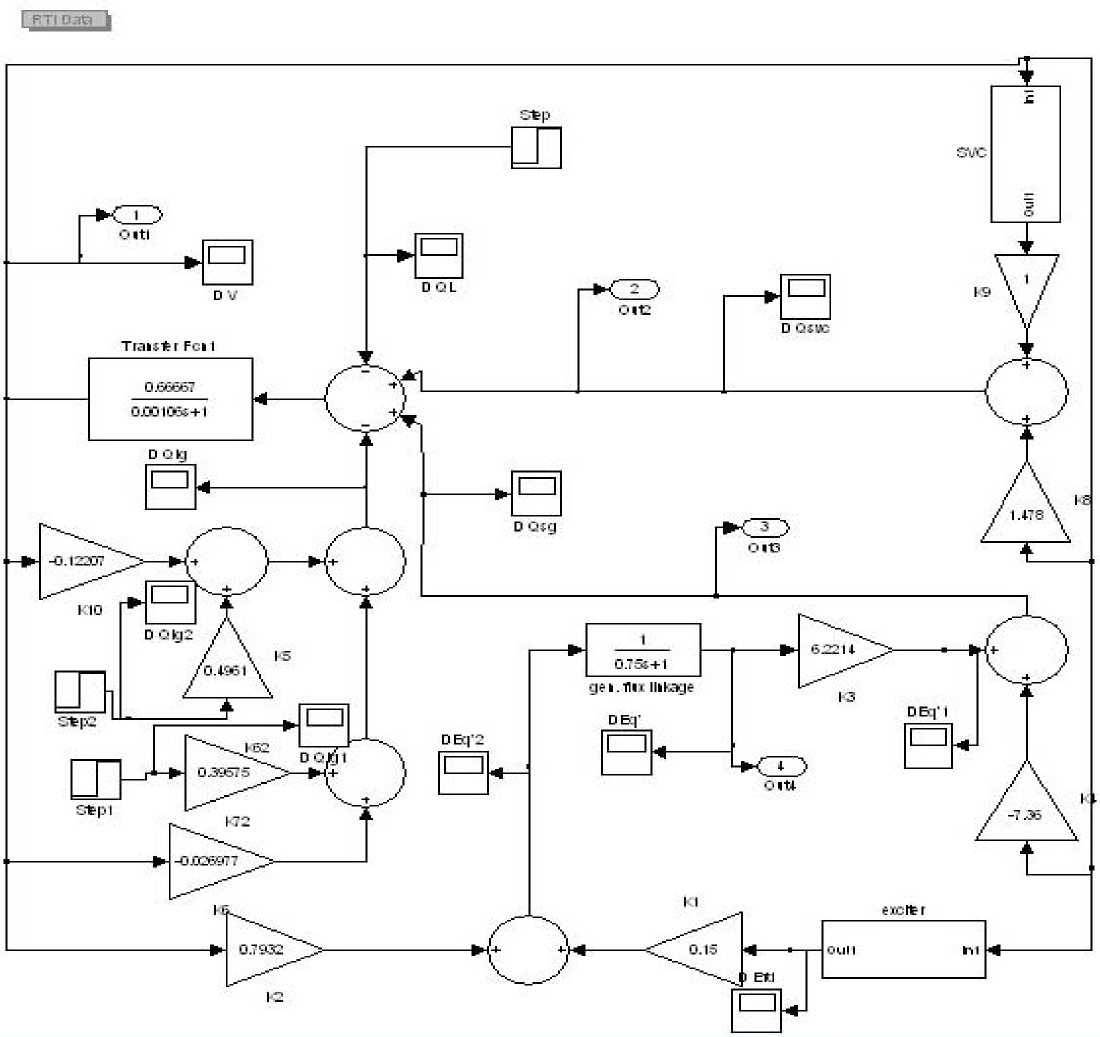


Figure 4. Real Time Interface Data of AWDHPS Model – III

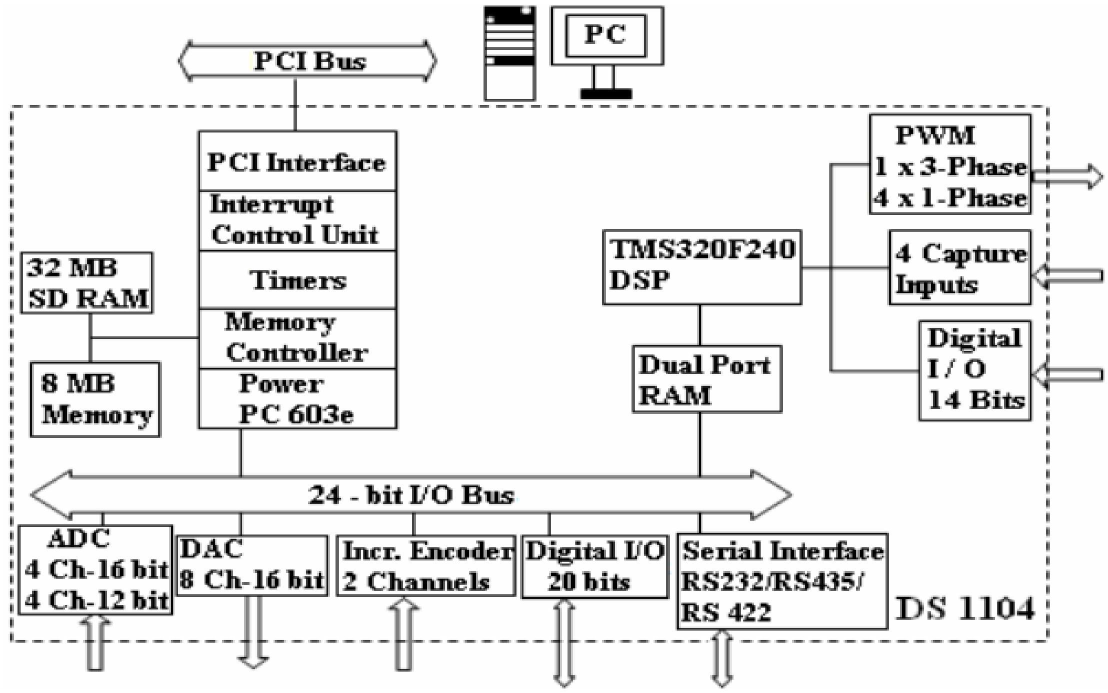


Figure 5. Block diagram of the DS 1104 controller board

4. Results and discussion

The simulink models used in the study are referred from (Bansal et al., 2004). The parameters used are given in Appendix I and II. The real time simulation study is carried out using the computer with dSPACE DS1104 R&D controller board. AWDHPS Model-I is implemented as per the steps given in section 3. The reactive power load change is a disturbance parameter in the model (It is assumed as a step block). The reactive power load change is compensated by the components such as SVC and SG in the model as given in equation (1).

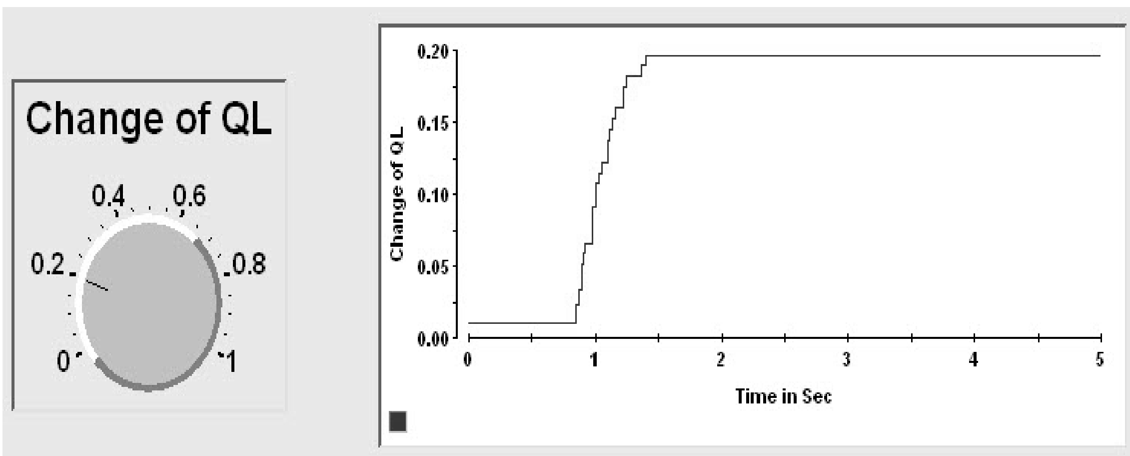
The reactive power load change is varied from 0 to 0.2 p.u. using the knob. The performance curves of various components such as SVC, SG and IG are shown in figure 6. The advantage of realtime study is that reactive power load change is varied from 0 to 0.2 p.u. with a time span of 0.85 sec to 1.5 sec and it is visually shown in the figure. It is found that the reactive power is supported fully by SVC for the reactive power change whereas the reactive power variations in SG and IG are very less. The performance of voltage variation under step change in load is also an important parameter considered in the study. Hence the time domain response specifications such as rise time, settling time, percent over shoot, peak time and steady state value of SVC for reactive power load changes from 0.01 to 1 p.u. are given in Table I.

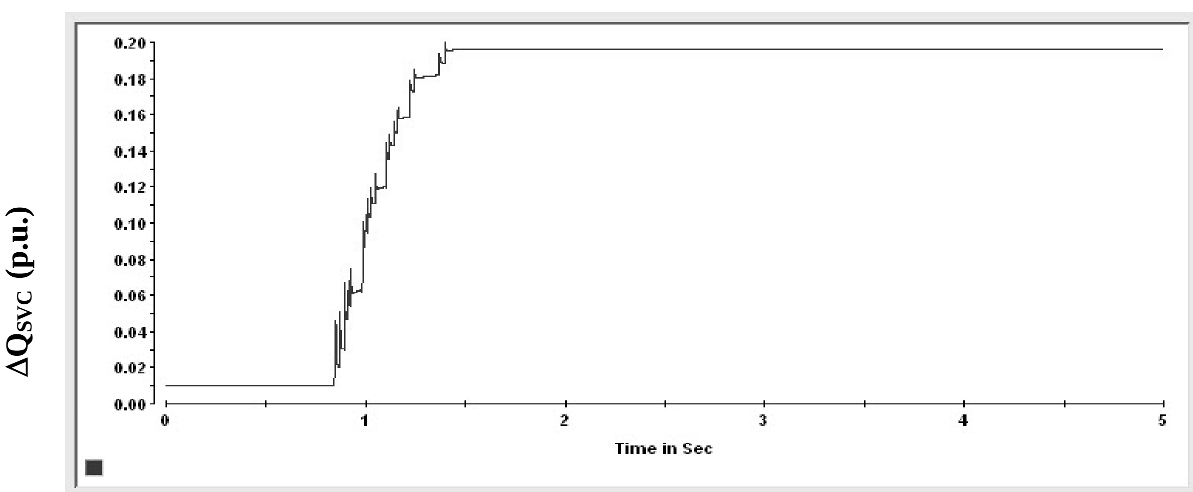
The two variable parameters such as change in reactive power load (ΔQ_L) and change in mechanical power input of the induction generator (ΔP_{IW}) are considered as step changes in AWDHPS Model-II. The real time study is carried out in such a way that the reactive power load change is varied from 0 to 0.2 p.u. with a span of 0.85 sec to 1.5 sec and ΔP_{IW} is varied from 0.01 to 0.02 p.u. with a span of 2.5 to 3 sec. The performance curves of SVC, SG, IG and voltage are shown in figure 7. The obtained response curves of ΔQ_{SVC} and ΔQ_{SG} are similar to AWDHPS Model-1. The variation in wind speed largely influences the response curve of ΔQ_{IG}. The obtained response curve of ΔQ_{IG} is from 0.005 to 0.009 p.u. with a span of 2.5 to 3 sec. The performance of voltage variation is high during reactive power load changes and less during change in mechanical power input of the induction generator respectively. Hence the time domain response specifications such as rise time, settling time, percent over shoot, peak time and steady state value of SVC for reactive power load changes from 0.01 to 1 p.u. and change in mechanical power input of the induction generator from 0.01 to 0.1 p.u. are given in Table II.

Three variable parameters are considered in AWDHPS Model-III. The real time study is carried out in such a way that the reactive power load change is varied from 0 to 0.2 p.u. with a span of 0.5 sec to 1 sec, ΔP_{IW1} is varied from 0 to 0.02 p.u. with a span of 2 to 2.5 sec and ΔP_{IW2} is varied from 0 to 0.02 p.u. with a span of 3.5 to 4.5 sec. The performance curves of SVC, SG, IG and voltage are shown in figure 8. The obtained response curves of ΔQ_{SVC} and ΔQ_{SG} are similar to AWDHPS Model-1 and II. The entire study is carried out in the time span 0.5 sec. to 4.5 sec. Even though the time span is large it is possible to observe the performance curve variations within a time span of 0.1 sec using the dSPACE environment. Hence a clear visual representation of the performance curves for smaller time span (0.1 sec.) is depicted in figure 7. The reactive power ratings of two induction generators are 0.13 and 0.04 p.u. respectively. Based on the rating of the induction generators, it is better to consider the variation of ΔP_{IW1} as higher value than ΔP_{IW2}. Hence, in the study ΔP_{IW1} is varied from 0.01 to 0.1 p.u. and ΔP_{IW2} is varied from 0.02 to 0.08 p.u. Moreover the reactive power load changes from 0.01 to 1 p.u. are considered. The time domain response specifications such as rise time, settling time, percent over shoot, peak time and steady state value of SVC for above variations are given in Table III.

From the time domain response specifications of SVC of the three models given in Table I, II and III it is observed that the peak time (t_p) are same. The percentage of peak overshoot is drastically reduced when ΔQ_L is varied from 0.5 to 1 p.u. because the maximum reactive power supported by SVC is assumed to be 0.85 p.u. Generally the rise time (t_r) increases as ΔQ_L is varied from 0.01 to 1 p.u. in all the three models. In the case of increase in ΔQ_L and ΔP_{IW} the settling time (t_s) decreases. The steady state value (Y_{SS}) of the SVC in AWDHPS Model - III is high because of the cumulative effect of three variable parameters of the model. Hence it is represented in a simple way by the expression, $Y_{ssI} < Y_{ssII} < Y_{ssIII}$.

Thus the AWDHPS Models are simulated in dSPACE environment and in this study the Knob is varied to increase or decrease the reactive power load and mechanical power of induction generators in real time environment for a desired time specification. The performance curves are visualized for the various components present in the models.





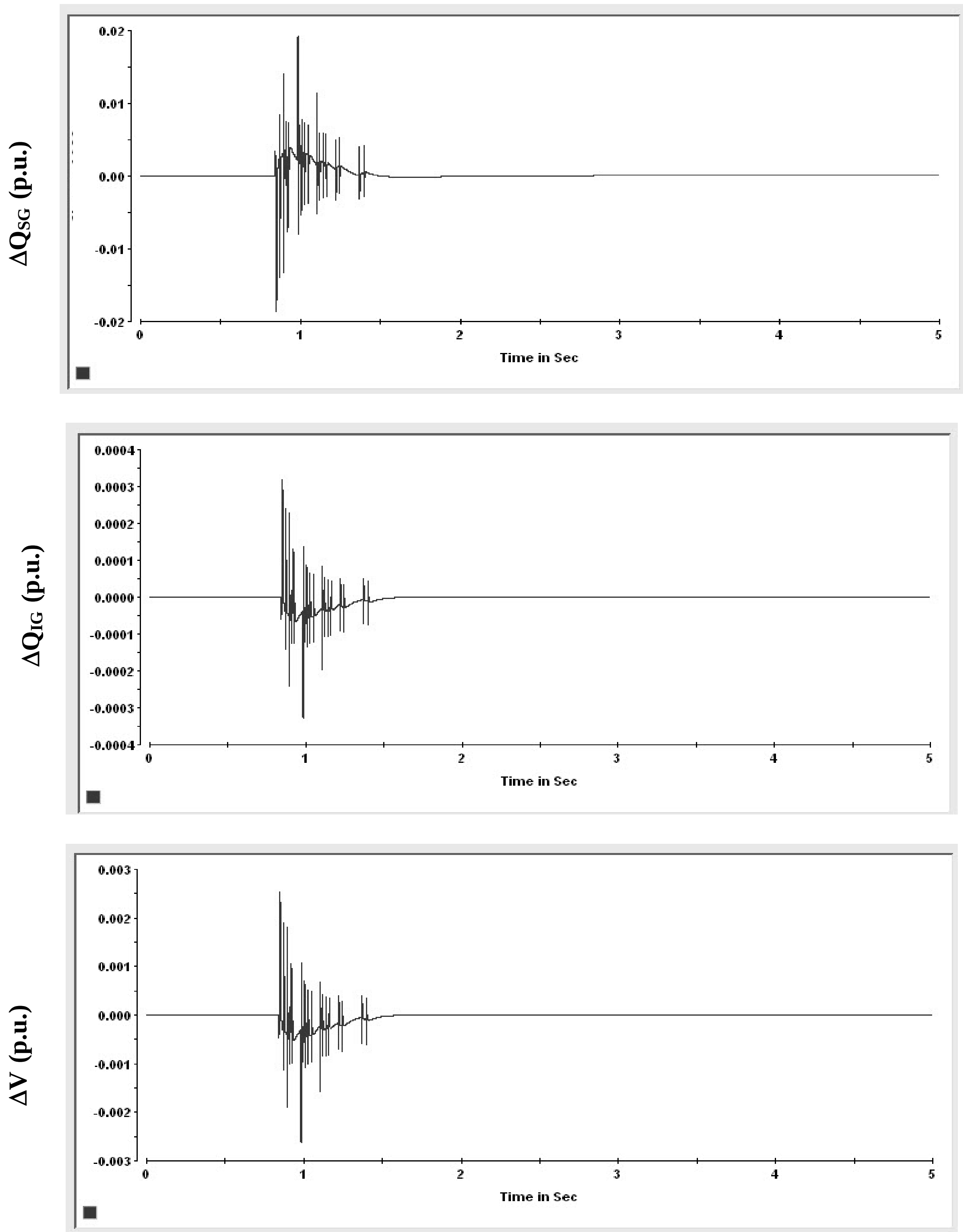
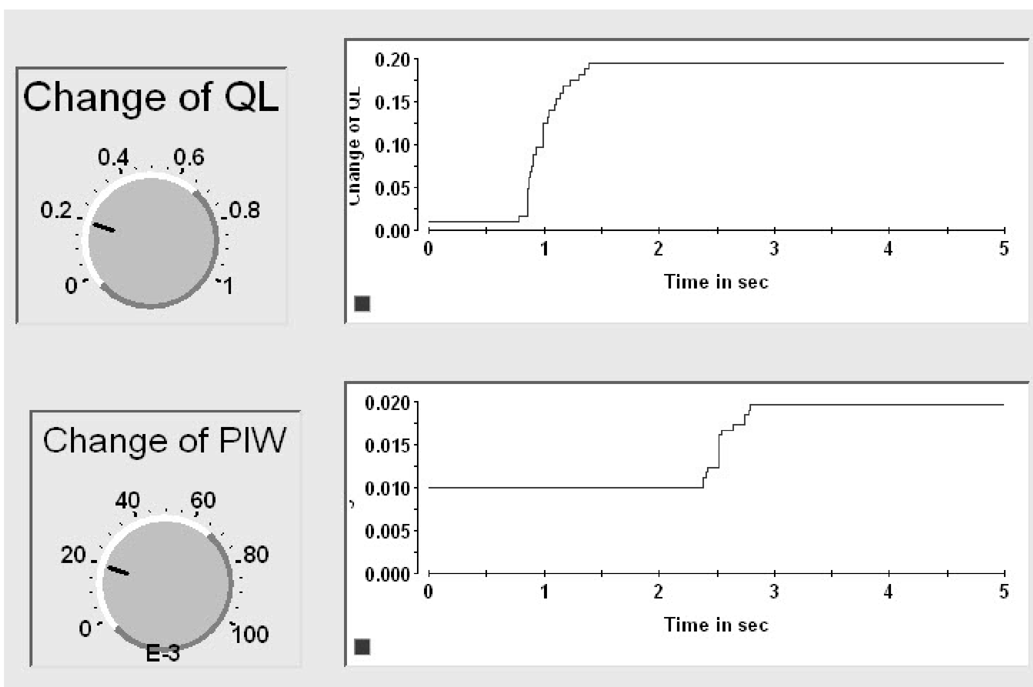
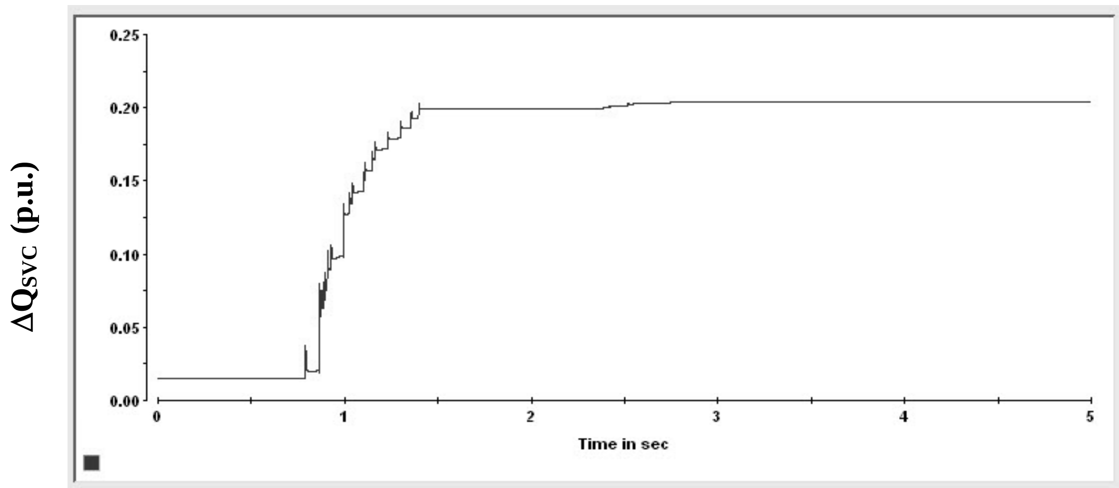


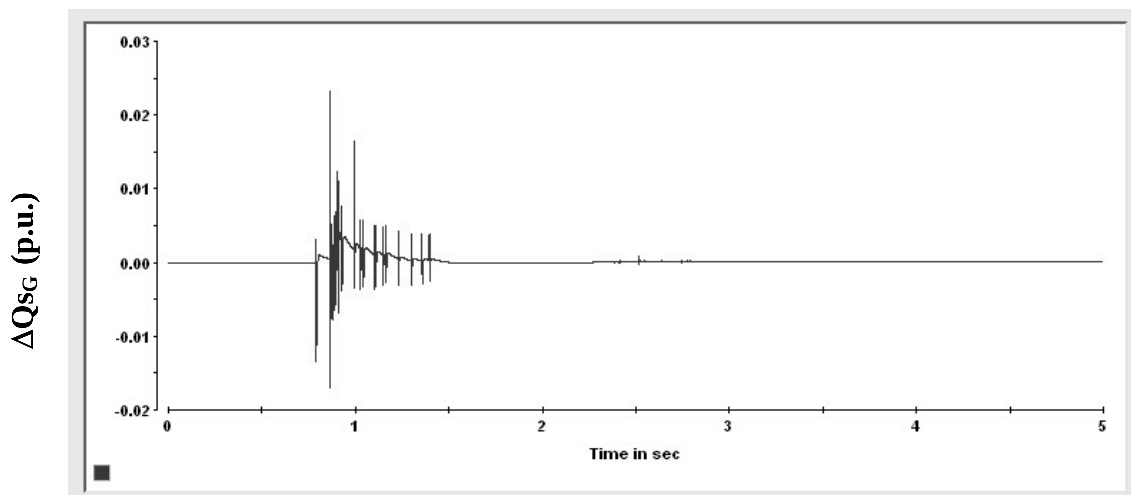
Figure 6. Real time responses of AWDHPS Model - I obtained from dSPACE environment

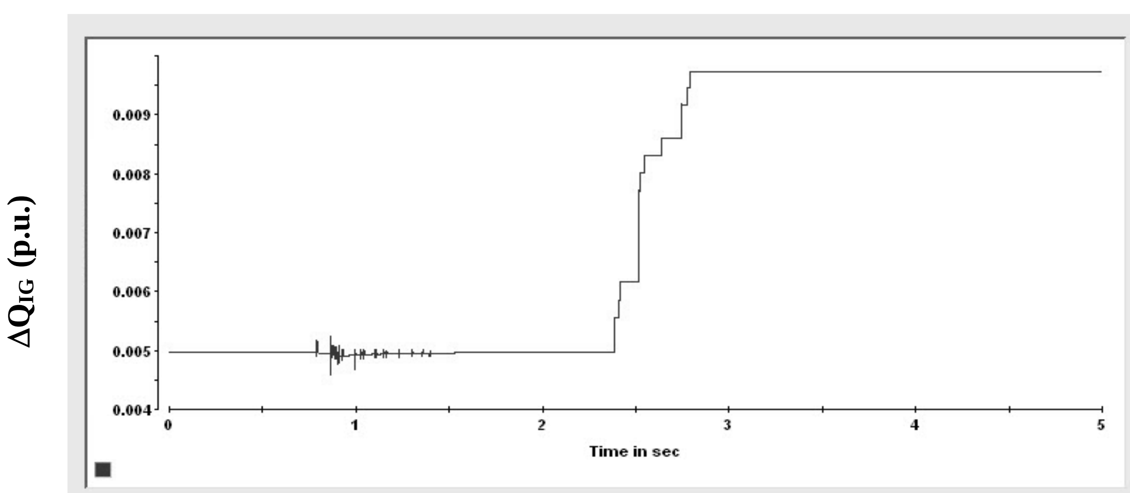
Table 1. Time Domain Specifications of SVC of AWDHPS Model – I

ΔQ_L in p.u.	0.01	0.05	0.1	0.5	0.8	0.9	1
Rise time (t_r) sec.	3.9e-004	3.4e-004	6.1e-005	0.0022	0.0043	0.0057	0.0078
Settling time (t_s) sec.	0.2159	0.2167	0.2098	0.1295	0.1313	0.1541	0.1768
Percent overshoot (Mp) %	129.7229	129.5521	101.0503	14.5814	5.7565	4.6580	3.8135
Peak time, (t_p) sec.	0.1038	0.1037	0.1038	0.1064	0.1096	0.1123	0.1180
Steady state value (Y_{ssI})	0.0098	0.0492	0.0988	0.4998	0.8028	0.9046	1.0074




ΔQSVC (p.u.)
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
Time in sec


ΔQSG (p.u.)
0.03
0.02
0.01
0.00
-0.01
-0.02
0
1
2
3
4
5
Time in sec


ΔQIG (p.u.)
0.009
0.008
0.007
0.006
0.005
0.004
0
1
2
3
4
5
Time in sec

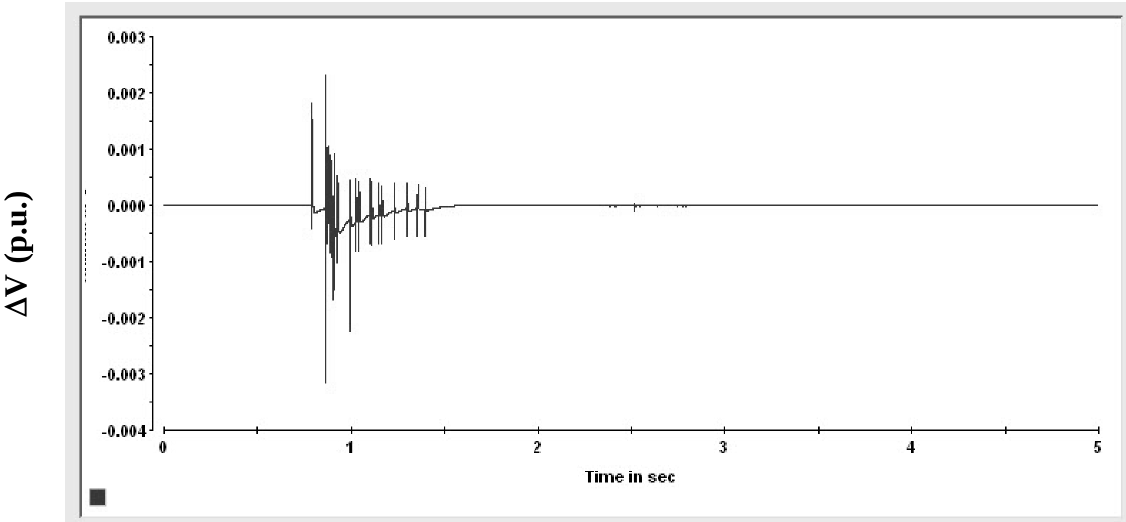
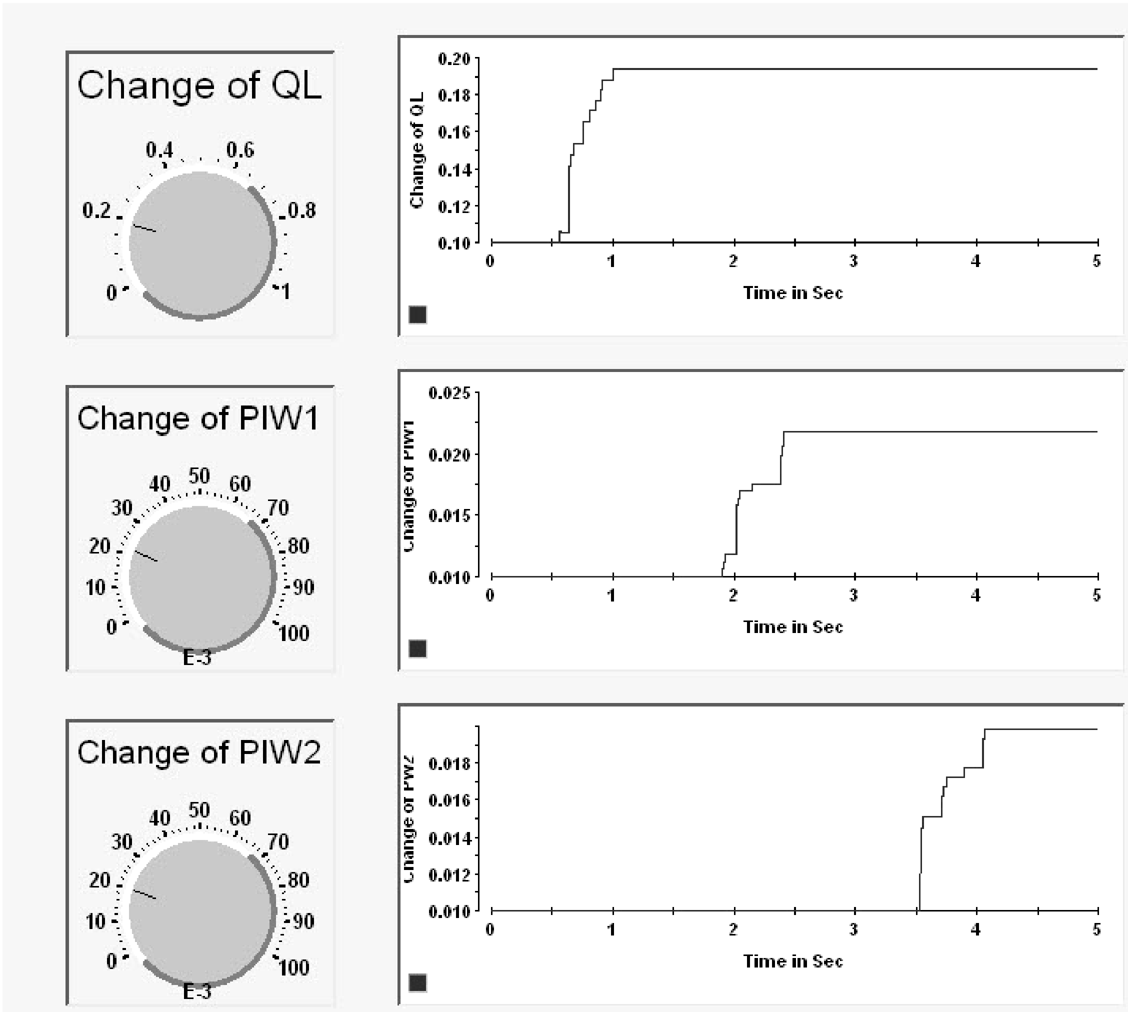
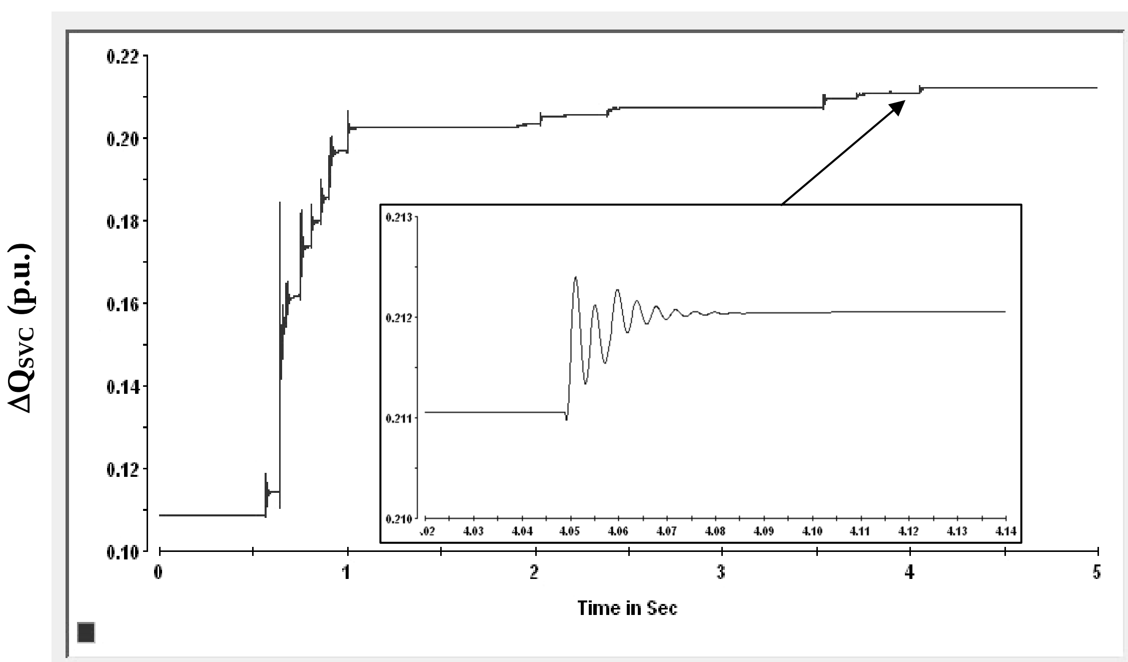


Figure 7. Real time responses of AWDHPS Model – II obtained from dSPACE environment

Table 2. Time Domain Specifications of SVC of AWDHPS Model – II

ΔQL in p.u.	0.01	0.05	0.1	0.5	0.8	0.9	1
ΔP_{IW} in p.u.	0.01	0.05	0.06	0.07	0.08	0.9	0.1
Rise time (t_r) sec.	3.5e-004	1.4e-015	5.1e-004	0.0023	0.0049	0.0063	0.0090
Settling time (t_s) sec.	0.2174	0.2147	0.2029	0.1256	0.1399	0.1648	0.1903
Percent overshoot (Mp) %	129.8616	119.6666	82.5985	12.9583	5.2171	4.1181	3.3706
Peak time, (t_p) sec.	0.1037	0.1037	0.1040	0.1062	0.1108	0.1138	0.1326
Steady state value (Y_{ssII})	0.0147	0.0737	0.1285	0.5348	0.8431	0.9503	1.0598


Change of QL
0.2
0.4
0.6
0.8
0
1
Change of QL
0.20
0.18
0.16
0.14
0.12
0.10
Time in Sec
Change of PIW1
E-3
Time in Sec
Change of PIW2
E-3
Time in Sec


ΔQSVC (p.u.)
0.22
0.20
0.18
0.16
0.14
0.12
0.10
Time in Sec

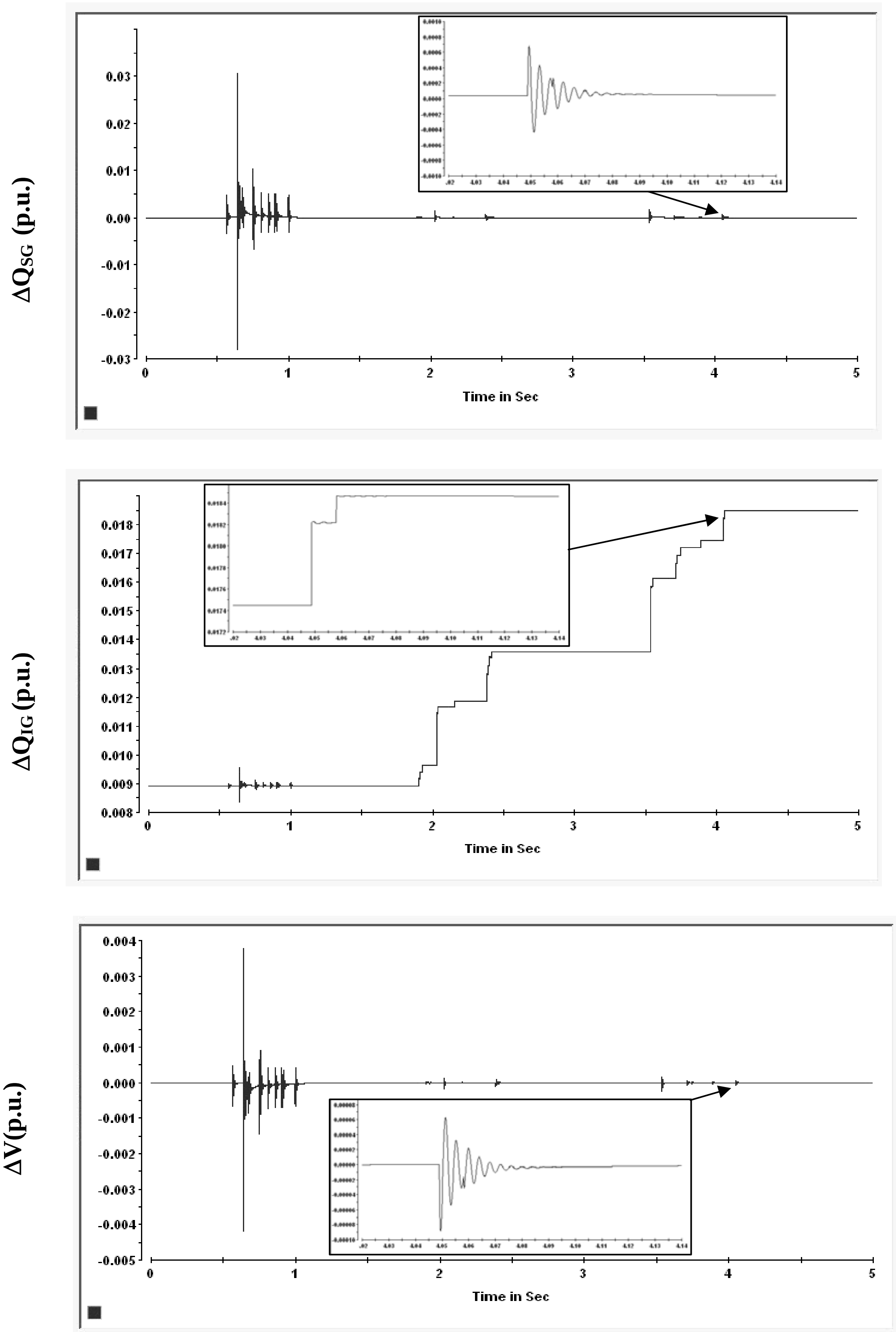


Figure 8. Real time responses of AWDHPS Model – III obtained from dSPACE environment

Table 3. Time Domain Specifications of SVC of AWDHPS Model – III

ΔQ_L in p.u.	0.01	0.05	0.1	0.5	0.8	0.9	1
ΔP_{IW1} in p.u.	0.01	0.05	0.06	0.07	0.08	0.9	0.1
ΔP_{IW2} in p.u.	0.02	0.03	0.04	0.05	0.06	0.07	0.08
Rise time (t_r) sec.	3.1e-004	1.1e-004	4.1e-004	0.0023	0.0051	0.0074	0.0102
Settling time (t_s) sec.	0.2168	0.2130	0.2025	0.1251	0.1502	0.1759	0.1256
Percent overshoot (Mp) %	128.9171	110.6292	72.7309	11.9457	4.9347	4.0826	0.0821
Peak time, (t_p) sec.	0.1036	0.1033	0.1034	0.1067	0.1113	0.1153	0.2447
Steady state value (Y_{ssIII})	0.0235	0.0836	0.1424	0.5531	0.8659	0.9776	1.0929

5. Conclusion

The MATLAB / simulink block diagrams of three models of AWDHPS are built in dSPACE real time environment. The reactive power control simulation was performed for three models of AWDHPS. The disturbance parameters in the models are the change in reactive power of the load (ΔQ_L), the change in mechanical power input of the induction generator (ΔP_{IW}) and the change in mechanical power input of two induction generators (ΔP_{IW1}, ΔP_{IW2}) respectively. The parameters are dynamically varied using knobs in dSPACE DS1104 R & D controller board. The real time performance curves of the hybrid power system were presented. The desired dynamic response behaviour of the three models is observed from the performance curves of the components present in them. Finally the important time domain response specifications such as settling time, percent over shoot and steady state value of SVC under study are tabulated.

APPENDIX I

CONSTANT VALUES OF AUTONOMOUS WIND-DIESEL HYBRID POWER SYSTEM

AWDHPS Model - I:

$K_1 = 0.15$, $K_2 = 0.793232$, $K_3 = 6.22143$, $K_4 = -7.358895$,
$K_5 = 0.126043$, $K_8 = 1.478$, $K_9 = 1.0$, $K_V = 0.6667$,
$K_\alpha = 0.446423$ and $T_V = 0.000106$ seconds.

AWDHPS Model - II:

$K_1 = 0.15$, $K_2 = 0.793232$, $K_3 = 6.22143$, $K_4 = -7.35889$,
$K_6 = 0.4961$, $K_7 = -0.122068$, $K_8 = 1.478$, $K_9 = 1.0$,
$K_V = 0.6667$, $K_\alpha = 0.446423$ and $T_V = 0.000106$ seconds.

AWDHPS Model – III:

$K_1 = 0.15$, $K_2 = 0.811744$, $K_3 = 6.36662$, $K_4 = -7.0915$,
$K_{61} = 0.4961$, $K_{62} = 0.39575$, $K_{71} = -0.122068$, $K_{72} = -0.026977$,
$K_8 = 1.52976$, $K_9 = 1.0$, $K_V = 0.66667$, and $T_V = 0.0001061$ seconds.

APPENDIX II

AUTONOMOUS WIND-DIESEL HYBRID POWER SYSTEM DATA

AWDHPS Parameters	**AWDHPS data - I**	**AWDHPS data – II**	
		IG_1	**IG_2**
AWDHPS Generation / Load Capacity			
Wind Capacity (kW)	150	150	50
Diesel Capacity (kW)	150	150	--
Load Capacity (kW)	250	300	
Base Power (kVA)	250	300	
Synchronous Generator			
P_{SG} (pu kW)	0.4	0.333	
Q_{SG} (pu kVAR)	0.2	0.162	
$E_{q'}$ (pu)	1.1136	0.9804	
δ^o	21.05	17.2483	
E_q (pu)	0.9603	1.1242	
V (pu)	1.0	1.0	
x_d (pu)	1.0	1.0	
x'_d (pu)	0.15	0.15	
T'_{do} (pu)	5.0	5.0	
Induction Generator			
P_{IG} (pu kW)	0.6	0.5	0.1667
Q_{IG} (pu kVAR)	0.189	0.1343	0.0426
P_{IW} (pu kW)	0.75	0.63	0.21
η_{IG} (%)	80	80	80
$r_1 = r_2'$ (pu)	0.19	0.19	0.55
$x_1 = x_2'$ (pu)	0.56	0.56	1.6
s (%)	-4.1	-3.49	-3.37
Load : P_L (pu kW)	1.0	1.0	
Q_L (pu kVAR)	**0.75**	**0.75**	
Pf (lag)	0.8	0.8	
Static Var Compensator			
$Q_{SVC} = Q_{IG}+Q_L-Q_{SG}$ (pu kVAR)	0.739	0.7649	
Q_C (pu kVAR)	0.85	0.87961	
α (radians)	2.443985	2.4452	
T_α (s)	0.005	0.005	
T_d (s)	0.001667	0.00167	
IEEE Type- I Excitation System			
K_A	40	40	
T_A (s)	0.05	0.05	
K_F	0.5	0.5	
T_F (s)	0.715	0.715	
K_E	1.0	1.0	
S_F (s)	0.0	0.0	
T_E (s)	0.55	0.55	

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