CHAPTER 5

REAL TIME PERFORMANCE STUDY OF HYBRID ENERGY SYSTEMS

5.1 INTRODUCTION

Autonomous power systems produce electricity near the load centers 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. The AWDHPS is becoming a viable and cost effective approach for remotely located communities. 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 continuity of supply.

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. 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. The SVCs are used to control the reactive power.
The important characteristic of an Artificial Neural Network (ANN) is its ability to solve a complex problem very efficiently. Since the knowledge related to the problem is spread in the neurons and the connection weights of links between neurons, the information are processed in parallel. The ANN has been applied to tune the SVC over a wide range of load models.

Real time study is performed with state of the art tools and real time digital simulators such as dSPACE, OPAL-RT and Real-Time Digital Simulator (RTDS). An 11 kW variable speed wind turbine control model is developed, using MATLAB/Simulink and tested with dSPACE DS 1103 (Mihet Popa 2008). OPAL-RT lab is used as hardware in the loop real-time control system platform, in solar panels operated with single-phase, 11-level, cascade, H-bridge, DC-AC grid-connected inverter (Filho 2010). A novel real-time simulation is performed for photovoltaic generation systems under real weather conditions using a RTDS (Minwon Park 2004).

In this Chapter, a real time performance study of automatic Reactive Power Control (RPC), in AWDHPS is carried out. The modeling of AWDHPS is carried out, using MATLAB/SIMULINK. Three models of AWDHPS such as constant speed/slip, variable speed/slip and multi wind-diesel are considered, to study RPC performance. The disturbance parameters in these AWDHPS models are, change in reactive power of load, change in mechanical power input of single induction generator and two induction generators. These parameters are dynamically varied, in control desk of dSPACE Software with DS1104 R & D controller board, under real time environment. A Multilayer Perceptron Artificial Neural Network (MPANN) controller is proposed for automatic RPC in AWDHPS. The reactive power control performance is studied by applying the proposed MPANN controller and a proportional plus integral (PI) controller individually, to tune the SVC. The performance results of MPANN and PI controllers are compared. The static and dynamic response curves are depicted. The reactive power deviations and time domain specifications are tabulated.
5.2 AWDHPS MODELS INVESTIGATED

The block diagram of the AWDHPS is shown in Figure 5.1. 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 SVC, tuned by the proposed MPANN controller.

![Block diagram of AWDHPS](image)

Figure 5.1 Block diagram of AWDHPS

The AWDHPS has been classified into three models, based on the disturbance variables of the system as shown in Figure 5.2.

(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 ($\Delta Q_L$) alone.
(ii) AWDHPS Model – II: It is a Dynamic Response Model (two variables). It is subjected to variation of both $\Delta Q_L$ and change in mechanical power input of induction generator ($\Delta P_{IW}$).

(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 $\Delta Q_L$ and change in mechanical power input of two induction generators ($\Delta P_{IW1}$, $\Delta P_{IW2}$).

![Autonomous Wind-Diesel Hybrid Power System]

Figure 5.2 Classification of AWDHPS based on number of disturbance variables

The equations governing the reactive power control of AWDHPS are given below. The change in system voltage due to reactive power disturbances of the AWDHPS is given by Equation (5.1),

$$
\Delta V(s) = \frac{K_v}{1 + sT_v} [\Delta Q_{sg}(s) + \Delta Q_{svc}(s) - \Delta Q_L(s) - \Delta Q_{ig}(s)]
$$

(5.1)
where,
\[
\begin{align*}
\Delta Q_{SG} &= \text{change in reactive power generated by SG (pu kVAR);} \\
\Delta Q_{SVC} &= \text{change in reactive power generated by SVC (pu kVAR);} \\
\Delta Q_L &= \text{change in reactive-power-load demand (pu kVAR);} \\
\Delta Q_{IG} &= \text{change in reactive power required by IG (pu kVAR);} \\
K_V &= \text{AWDHPS gain constant;} \\
T_V &= \text{AWDHPS time constant in seconds.}
\end{align*}
\]

The change in reactive power of the synchronous generator, induction generator and SVC are given by the Equations (5.2), (5.3) and (5.4) respectively.

\[
\begin{align*}
\Delta Q_{SG}(s) &= K_3\Delta E_q(s) + K_4\Delta V(s) \quad (5.2) \\
\Delta Q_{IG}(s) &= K_7\Delta V(s) + K_8\Delta P_{iW}(s) \quad (5.3) \\
\Delta Q_{SVC}(s) &= K_8\Delta V(s) + K_9\Delta B_{SVC}(s) \quad (5.4)
\end{align*}
\]

where
\[
\begin{align*}
\Delta B_{SVC} &= \text{change in reactive susceptance of SVC;} \\
\Delta E_q &= \text{change in internal armature emf under transient conditions of SG.}
\end{align*}
\]

The exponent \(\eta_q\) of reactive power load-voltage characteristic is determined by Equation (5.5),

\[
\eta_q = \frac{V\Delta Q_L}{Q_L\Delta V} \quad (5.5)
\]

where, \(V = \text{system voltage} ; \quad \Delta V = \text{change in system voltage.}\)
The simulink model of AWDHPS - III is as shown in Figure 5.3. The three simulink models of AWDHPS are simulated in the MATLAB environment. The reactive power control performance is studied by applying the proposed MPANN controller and a proportional plus integral (PI) controller, individually. The constant values of three AWDHPS Models are given in Appendix 2. The AWDHPS data – I and II are given in the Appendix 3. The simulation is carried out using the AWDHPS data – I for AWDHPS Model – I and AWDHPS Model - II. The AWDHPS data – II is used for AWDHPS Model - III. Then the MATLAB/simulink models of AWDHPS are built in dSPACE real time environment. 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. The individual performance of the proposed MPANN controller and the PI controller in the above real time environment are recorded.

Figure 5.3 Simulink model of AWDHPS model – III
5.3 MPANN CONTROLLER FOR TUNING OF SVC

The proposed MPANN controller consists of only one neuron in each layer and undergoes intensive learning for updating the weights. The non-linearity is imposed in the hidden layer alone by the log-sigmoid transfer function. The log-sigmoid function is taken because its output always lies between 0 and 1. Hence the control signal also lies between 0 and 1. As a result the output from hidden neurons is 0.5 when the input to the proposed MPANN is zero. The output from the hidden neurons with the output layer weights is established as a result of iteration. The output provides a control signal to make the steady state error as zero. The input and back propagation equations governing the MPANN controller are given below. The flow chart of algorithm is shown in Figure 5.4.

The change in system voltage and the change in reactive power load demand are the input (\(I_P\)) to the proposed MPANN controller and is given by Equation (5.6),

\[ I_P = \Delta V + \Delta Q_L \quad (5.6) \]

The input (\(I\)) to the neurons of hidden layer is given by Equation (5.7),

\[ I = I_P \times W_1 \quad (5.7) \]

The output (\(O_H\)) from hidden layer after passing into the log-sigmoid transfer function is given by Equation (5.8),

\[ O_H = \frac{1}{1+e^{-I}} \quad (5.8) \]

The control signal (\(C_S\)) from the output layer is determined by Equation (5.9),

\[ C_S = O_H \times W_2 \quad (5.9) \]
The weights ($\Delta W_1$) and ($\Delta W_2$) of hidden layer and output layers respectively, are restructured by Equations (5.10) and (5.11),

\[
\begin{align*}
\Delta W_1 &= (-1) \times \gamma \times \Delta_1 + (\theta \times \Delta W_{1(PREV)}) \\
\Delta W_2 &= (-1) \times \beta \times O_H + (\theta \times \Delta W_{2(PREV)})
\end{align*}
\] (5.10) (5.11)

where, $\gamma =$ learning rate of hidden layer; $\theta =$ momentum constant; $\beta =$ learning rate of output layer

Figure 5.4 Flow chart of the MPANN control process

In AWDHPS Model – I, II and III the values of $\gamma$, $\beta$ and $\theta$ are 0.6, 0.0001 and -1 respectively. These values were achieved through trial and error method. The derivative ($\Delta_1$) of the output of the hidden layer with regard to its associated input weights is calculated by Equation (5.12),

\[
\Delta_1 = O_H \times (1 - O_H) \times I_p
\] (5.12)
5.4 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. The Real Time Interface data of AWDHPS Model - III is shown in Figure 5.5. The Figure 5.6 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 5.3.
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 5.5 Real time interface data of AWDHPS model – III
5.5 RESULTS AND DISCUSSION

The simulink models used in the study have been dealt at length in (Bansal 2008). The parameters used are given in Appendix 2 and 3. The real time simulation study is carried out using the computer with the dSPACE DS1104 R&D controller board. The three AWDHPS Models are implemented as per the steps given in section 5.4 of this chapter. Even though the time span of entire analysis is large it is possible to observe the performance curve variations within a time span of 0.01 sec using the dSPACE environment. Hence a clear visual representation of the performance curves for smaller time span (0.01 sec.) is depicted in Figures 5.7(a to e), 5.8(a to e) and 5.9(a to e).
5.5.1 Reactive Power Deviations

The static and dynamic real time response curves of AWDHPS Models–I, II and III obtained by proposed MPANN for a wide variation of the disturbance parameters ($\Delta Q_L$, $\Delta P_{IW}$, $\Delta P_{IW1}$ and $\Delta P_{IW2}$) are shown in Figures 5.7, 5.8 and 5.9 respectively. The maximum deviations of various parameters, ($\Delta V$, $\Delta Q_{SG}$, $\Delta Q_{SVC}$ and $\Delta Q_{IG}$), obtained through ANN in MATLAB/simulink are given only for AWDHPS Models - II and III, with $\eta_q$ values 3.25 and 1.25 in (Bansal 2008). The maximum deviations of the parameters of AWDHPS Models - II and III, obtained by proposed MPANN controller, in dSPACE environment, for same values of $\eta_q$ are compared with (Bansal 2008) in Tables 5.1 and 5.2 respectively in order to establish its performance. The change in system voltage ($\Delta V$) is significantly reduced by proposed MPANN controller.

Table 5.1 Comparison of maximum deviations of various parameters of AWDHPS model - II

<table>
<thead>
<tr>
<th>Parameters of AWDHPS - II</th>
<th>Type of controller</th>
<th>For $\eta_q = 3.25$ and $\Delta Q_l$ (p.u.) = 0.031</th>
<th>For $\eta_q = 1.25$ and $\Delta Q_l$ (p.u.) = 0.029</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta V$ (p.u.)</td>
<td>ANN (Bansal 2008)</td>
<td>-0.001900</td>
<td>-0.001564</td>
</tr>
<tr>
<td></td>
<td>Proposed MPANN</td>
<td>-0.000160</td>
<td>-0.000148</td>
</tr>
<tr>
<td>$\Delta Q_{SG}$ (p.u.)</td>
<td>ANN (Bansal 2008)</td>
<td>0.0140</td>
<td>0.0115</td>
</tr>
<tr>
<td></td>
<td>Proposed MPANN</td>
<td>0.0052</td>
<td>0.0056</td>
</tr>
<tr>
<td>$\Delta Q_{SVC}$ (p.u.)</td>
<td>ANN (Bansal 2008)</td>
<td>0.0204</td>
<td>0.0202</td>
</tr>
<tr>
<td></td>
<td>Proposed MPANN</td>
<td>0.0289</td>
<td>0.0260</td>
</tr>
<tr>
<td>$\Delta Q_{IG}$ (p.u.)</td>
<td>ANN (Bansal 2008)</td>
<td>0.0032</td>
<td>0.0032</td>
</tr>
<tr>
<td></td>
<td>Proposed MPANN</td>
<td>0.003</td>
<td>0.003</td>
</tr>
</tbody>
</table>
Table 5.2  Comparison of maximum deviations of various parameters of AWDHPS model – III

<table>
<thead>
<tr>
<th>Parameters of AWDHPS-III</th>
<th>Type of controller</th>
<th>For $\eta_q = 3.25$ and $\Delta Q_L$ (p.u.) = 0.034</th>
<th>For $\eta_q = 1.25$ and $\Delta Q_L$ (p.u.) = 0.031</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta V$ (p.u.)</td>
<td>ANN (Bansal 2008)</td>
<td>-0.002089</td>
<td>-0.001708</td>
</tr>
<tr>
<td></td>
<td>Proposed MPANN</td>
<td>-0.000189</td>
<td>-0.000173</td>
</tr>
<tr>
<td>$\Delta Q_{SG}$ (p.u.)</td>
<td>ANN (Bansal 2008)</td>
<td>0.0148</td>
<td>0.0121</td>
</tr>
<tr>
<td></td>
<td>Proposed MPANN</td>
<td>0.0047</td>
<td>0.0041</td>
</tr>
<tr>
<td>$\Delta Q_{SVC}$ (p.u.)</td>
<td>ANN (Bansal 2008)</td>
<td>0.0215</td>
<td>0.0210</td>
</tr>
<tr>
<td></td>
<td>Proposed MPANN</td>
<td>0.0308</td>
<td>0.0284</td>
</tr>
<tr>
<td>$\Delta Q_{IG}$ (p.u.)</td>
<td>$\Delta Q_{IG1}$ (p.u.)</td>
<td>ANN (Bansal 2008)</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>Proposed MPANN</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>$\Delta Q_{IG2}$ (p.u.)</td>
<td>ANN (Bansal 2008)</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Proposed MPANN</td>
<td>0.001</td>
<td>0.001</td>
</tr>
</tbody>
</table>

5.5.2  Time Domain Specifications

5.5.2.1  Performance of MPANN in AWDHPS model - I

The reactive power load change is a disturbance parameter in the AWDHPS Model-I (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 5.1. The reactive power load change is varied from 0.01 to 0.04 p.u. using the knob. The performance curves of various components such as SVC, SG and IG are shown in Figure 5.7 (a to e). The advantage of real time study is that reactive power load change is varied from 0.01 to 0.04
p.u. with a time span of 0.85 sec to 1.8 sec and it is visually shown in the Figure 5.7 (a to e). 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 percent over shoot, settling time, rise time, peak time and steady state value of SVC for reactive power load changes from 0.01 to 0.1 p.u. are observed. The time domain specifications of SVC obtained by the proposed MPANN controller is compared with a PI controller and tabulated in Table 5.3. The performance of proposed MPANN controller is found to be good.

Figure 5.7 (Continued)
Figure 5.7 (a to e) Real time responses of the AWDHPS model - I obtained by MPANN
Table 5.3  Comparison of time domain specifications of SVC obtained by MPANN and PI controller for AWDHPS model – I

<table>
<thead>
<tr>
<th>( \Delta Q_t ) in p.u.</th>
<th>0.01</th>
<th>0.05</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Controller</td>
<td>Proposed MPANN</td>
<td>PI</td>
<td>Proposed MPANN</td>
</tr>
<tr>
<td>Percent overshoot (Mp) %</td>
<td>4.0421</td>
<td>129.7229</td>
<td>3.9651</td>
</tr>
<tr>
<td>Settling time (t_s) sec.</td>
<td>0.1487</td>
<td>0.2159</td>
<td>0.1964</td>
</tr>
<tr>
<td>Rise time (t_r) sec.</td>
<td>0.8375</td>
<td>3.9e-004</td>
<td>0.8324</td>
</tr>
<tr>
<td>Peak time, (t_p) sec.</td>
<td>0.1767</td>
<td>0.1038</td>
<td>0.1694</td>
</tr>
<tr>
<td>Steady state value (Y_{ss})</td>
<td>0.0072</td>
<td>0.0098</td>
<td>0.0362</td>
</tr>
</tbody>
</table>

5.5.2.2 Performance of MPANN in AWDHPS model – II

The two variable parameters such as change in reactive power load (\( \Delta Q_L \)) and change in mechanical power input of the induction generator (\( \Delta P_{Iw} \)) 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 0.01 to 0.04 p.u. with a span of 1 sec to 1.3 sec and \( \Delta P_{Iw} \) is varied from 0.01 to 0.04 p.u. with a span of 2.2 to 2.65 sec. The performance curves of SVC, SG, IG and voltage are shown in Figure 5.8 (a to e). The obtained response curves of \( \Delta Q_{SVC} \) and \( \Delta Q_{SG} \) are similar to AWDHPS Model-1. The variation in wind speed largely influences the response curve of \( \Delta Q_{IG} \). The obtained response curve of \( \Delta Q_{IG} \) is from 0.0127 to 0.01312 p.u. with a span of 2.604 to 2.605 sec. The performance of voltage variation is high during reactive power load changes and less during change in mechanical power.
input of induction generator respectively. Hence, the time domain response specifications such as percent overshoot, settling time, rise time, peak time and steady state value of SVC for reactive power load changes from 0.01 to 0.1 p.u. and change in mechanical power input of the induction generator from 0.01 to 0.06 p.u. were observed. The time domain specifications of SVC obtained by the proposed MPANN controller was compared with a PI controller and tabulated in Table 5.4. The proposed MPANN controller has shown good performance over the PI controller.

![Graphs showing time domain response of SVC](image)

**Figure 5.8 (Continued)**
Figure 5.8 (a to e) Real time responses of the AWDHPS model - II obtained by MPANN
Table 5.4  Comparison of time domain specifications of SVC obtained by MPANN and PI controller for AWDHPS model – II

<table>
<thead>
<tr>
<th>( \Delta Q_L ) in p.u.</th>
<th>0.01</th>
<th>0.05</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta P_{IW} ) in p.u.</td>
<td>0.01</td>
<td>0.03</td>
<td>0.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Controller</th>
<th>Proposed MPANN</th>
<th>PI</th>
<th>Proposed MPANN</th>
<th>PI</th>
<th>Proposed MPANN</th>
<th>PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Overshoot (( Mp )) %</td>
<td>4.0865</td>
<td>129.861</td>
<td>3.9725</td>
<td>119.666</td>
<td>3.9664</td>
<td>82.598</td>
</tr>
<tr>
<td>Settling time (( t_s )) sec.</td>
<td>0.1450</td>
<td>0.2174</td>
<td>0.1290</td>
<td>0.2147</td>
<td>0.1094</td>
<td>0.2029</td>
</tr>
<tr>
<td>Rise time (( t_r )) sec.</td>
<td>0.8372</td>
<td>3.5e-004</td>
<td>0.8357</td>
<td>1.4e-015</td>
<td>0.8081</td>
<td>5.1e-004</td>
</tr>
<tr>
<td>Peak time (( t_p )) sec.</td>
<td>0.1763</td>
<td>0.1037</td>
<td>0.1742</td>
<td>0.1037</td>
<td>0.1323</td>
<td>0.1040</td>
</tr>
<tr>
<td>Steady state value (( Y_{ss} ))</td>
<td>0.0108</td>
<td>0.0147</td>
<td>0.0216</td>
<td>0.0737</td>
<td>0.0947</td>
<td>0.1285</td>
</tr>
</tbody>
</table>

5.5.2.3  Performance of MPANN in AWDHPS model - III

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 0.01 to 0.04 p.u. with a span of 0.96 sec to 1.4 sec, \( \Delta P_{IW1} \) is varied from 0.01 to 0.04 p.u. with a span of 2.2 to 2.5 sec and \( \Delta P_{IW2} \) is varied from 0.01 to 0.04 p.u. with a span of 3.4 to 3.6 sec. The performance curves of SVC, SG, IG and voltage are shown in Figure 5.9 (a to e). The obtained response curves of \( \Delta Q_{SVC} \) and \( \Delta Q_{SG} \) are similar to AWDHPS Model-1 and II. The entire study is carried out in the time span 0.85 sec to 3.6 sec. 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 \( \Delta P_{IW1} \) as higher value than \( \Delta P_{IW2} \). Hence, in the study, \( \Delta P_{IW1} \) is varied from 0.01 to 0.06 p.u. and \( \Delta P_{IW2} \) is varied from 0.03 to 0.08 p.u. Moreover the reactive power load changes from 0.01 to 0.1 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 were observed. The time domain specifications of SVC obtained by the proposed MPANN controller was compared with a PI controller and tabulated in Table 5.5. The performance of proposed MPANN controller is found to be better than PI controller.

![Figure 5.9 (Continued)](image-url)
Figure 5.9(a to e) Real time responses of the AWDHPS model - III obtained by MPANN
Table 5.5  Comparison of time domain specifications of SVC obtained by MPANN and PI controller for AWDHPS model – III

<table>
<thead>
<tr>
<th>Type of Controller</th>
<th>ΔQ_L in p.u.</th>
<th>0.01</th>
<th>0.05</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ΔP_{IW} in p.u.</td>
<td>0.01</td>
<td>0.03</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>ΔP_{IW2} in p.u.</td>
<td>0.03</td>
<td>0.05</td>
<td>0.08</td>
</tr>
<tr>
<td>Percent Overshoot (Mp) %</td>
<td>Proposed MPANN</td>
<td>4.2165</td>
<td>128.9171</td>
<td>4.1021</td>
</tr>
<tr>
<td>Settling time (t_s) sec.</td>
<td>Proposed MPANN</td>
<td>0.1289</td>
<td>0.2168</td>
<td>0.1162</td>
</tr>
<tr>
<td>Rise time (t_r) sec.</td>
<td>PI</td>
<td>0.8320</td>
<td>3.1e-004</td>
<td>0.8200</td>
</tr>
<tr>
<td>Peak time, (t_p) sec.</td>
<td>PI</td>
<td>0.1673</td>
<td>0.1036</td>
<td>0.1492</td>
</tr>
<tr>
<td>Steady state value (Y_{ss})</td>
<td>Proposed MPANN</td>
<td>0.0194</td>
<td>0.0235</td>
<td>0.0614</td>
</tr>
</tbody>
</table>

From the time domain response specifications of SVC of the three models given in Table 5.3, 5.4 and 5.5, it is observed that the peak time (t_p) are nearly same. The percentage of peak overshoot is reduced when ΔQ_L is varied from 0.01 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.

5.6 CONCLUSION

This chapter presented the automatic reactive power control of AWDHPS by tuning SVC using the proposed MPANN controller. The MATLAB/simulink models of three different AWDHPS are considered, by integrating the proposed MPANN as the controller, for tuning the SVC. The potential of proposed MPANN controller is demonstrated by varying the disturbance parameters such as change in reactive power of the load ($\Delta Q_L$), the change in mechanical power input of the single induction generator ($\Delta P_{IW}$) and the change in mechanical power input of two induction generators ($\Delta P_{IW1}$, $\Delta P_{IW2}$) in three different AWDHPS models. Then, the above MATLAB/simulink models of AWDHPS are built in dSPACE real time environment. The real time assessment of the models is carried out by dynamically varying the parameters in control desk of dSPACE software with DS1104 R & D controller board mounted in personal computer. The proposed MPANN controller in dSPACE environment has performed well compared to the ANN controller in MATLAB/simulink present in recent literature. Specifically, the change in system voltage ($\Delta V$) is significantly reduced by the MPANN controller. The time domain specifications of SVC obtained by the MPANN controller and a PI controller are compared. The proposed MPANN controller has shown good performance over the PI controller. The static and dynamic response curves are depicted. The reactive power deviations and time domain specifications are tabulated.