CHAPTER 9

MPPT SIMULATION RESULTS AND ANALYSIS WITH DC MOTOR PUMP

9.1 Introduction

9.2 Simulation Curves of P&O Algorithm using Input Sensing Direct Control Method with CUK Converter and DC Motor Pump

9.3 Simulation Curves of Increment Conductance Algorithm using Input Sensing Direct Control Method with CUK Converter and DC Motor Pump

9.4 Simulation Curves of Decrement Resistance Algorithm using Input Sensing Direct Control Method with CUK Converter and DC Motor Pump

9.5 Simulation Curves of P&O Algorithm using Output Sensing Direct Control Method with CUK Converter and DC Motor Pump

9.6 Energy utilization efficiency of direct control method using P&O MPPT with variable resistive load

9.7 Comparative Analysis of energy utilization efficiency and water pumped

9.8 Comparative Analysis between Direct Couple and Direct Control Methods for the Application DC Motor Pump

9.9 Conclusion
9.1 INTRODUCTION

In this chapter, the DC motor pump is connected with PV module through MPPT and the system is implemented in MATLAB using direct control methods. The simulation is done with three different MPPT algorithms. The direct control method adjusts the duty cycle within the MPP tracking algorithm. The way to adjust the duty cycle is totally based on the theory of load matching. When the value of $R_{load}$ (Load of DC motor pump) matches with the value of $R_{opt}$ (optimal resistance of PV module), the maximum power transfer from PV to the load will occur. These two are, however, independent and rarely matches in practice. The goal of the MPPT is to match the impedance of load to the optimal impedance of PV module.

9.2 SIMULATION CURVES OF P&O ALGORITHM USING INPUT SENSING DIRECT CONTROL METHOD WITH CUK CONVERTER AND DC MOTOR PUMP

In this simulation system, the PV module BP SX 150S consist with the ideal (loss-less) Cuk converter, the MPPT control, and a DC motor pump. This direct control method employs the P&O algorithm to locate the MPP. The MATLAB function that models the PV module is the following

$$I_a = bp_{sx150s}(V_a, G, T) \quad (9.1)$$

The function, $bp_{sx150s}(V_a, G, T)$, calculates the module current ($I_a$) for the module voltage ($V_a$), irradiance ($G$ in KW/m$^2$), and module temperature ($T$ in °C). The operating point of PV module is located by its relationship to the load resistance ($R_{load}$) as explained in section 5.6. The various simulation results of using P&O MPPT with input sensing direct control method are given in Figure 9.1.
(a) Input Sensin Direct Control Method using P&O Algorithm

Module Voltage (V)

Module Current (A)

(b) Input Sensin Direct Control Method using P&O Algorithm

Module Voltage (V)
(c) Input Sensin Direct Control Method using P&O Algorithm

Output Power (W) vs. Duty Cycle

Output Voltage (V) vs. Output Current (A)

(d) Input Sensin Direct Control Method using P&O Algorithm
(e) Input Sensin Direct Control Method using P&O Algorithm

(f) Input Sensin Direct Control Method using P&O Algorithm
Figure 9.1: Simulation results of input sensing direct control method using P&O algorithm

The irradiance is increased linearly from 200W/m² to 1000W/m² with the same rate of 0.3W/m² per sample. Figures 9.1(a) & 9.1(b) show that the
traces of operating points are staying close to the MPPs throughout the simulation. Figure 9.1(c) shows the relationship between the output power of converter and its duty cycle. The output power of converter is increasing with duty cycle upto $D < 0.5$. Figure 9.1(d) shows the current and voltage relationship of converter output. It shows that the output current rises rapidly with increasing voltage until the current is sufficient to create enough torque to start the motor. Once it starts to run, the back emf takes effect and drops the current, therefore the current rises slowly with increasing voltage. Figure 9.1(e) shows the curve of flow rate of pump vs. time. In the starting the flow rate pump increases with time but after full radiation (1000W/m²), approximately after one hour the flow rate of pump is constant. Figure 9.1(f) shows the curve of load of DC motor pump vs. output voltage of converter. It is shown that the Rload curve is nonlinear and increases with increasing converter voltage. Figure 9.1(g) shows the two curves, one curve shows the extracted power or tracking power from the theoretical power of the PV module, and another curve shows the output power of converter. It is seen from both curve that how the total extracted power is transferred to the load by the converter. Figure 9.1(h) shows the power v/s. time curve, one curve is the output power of convert with respect to time while another curve is the input power of converter with respect to time. Both curves are overlap to each other because in the system CUK converter is considers as idle (loss less), so the input power is completely transferred to the load by the converter.

9.2.1 Energy Utilization Efficiency of PV Module

Energy utilization efficiency is the ratio of utilization energy of PV module to the theoretical energy (total maximum points energy) of the PV module. Here in this section, The DC motor pump is coupled with the PV module using input sensing P&O MPPT, so the utilization power of the PV module is the output power of CUK converter (In other words, the power consumed by the DC motor pump). The utilization energy (utilization energy
Utilization energy of the PV module

\[= 0.5 \times 149.8 \times 0.9269 + 149.8 \times 11.0731\]

\[= 69.42 + 1658.75\]

\[= 1728.2\text{Wh}\]

\[\approx 1730.3\text{Wh (by simulation program)}\] \hspace{1cm} (9.2)

The Theoretical Energy of the PV module = 1732.3Wh (from section 2.9)

\[
\text{Energy Utilization Efficiency } = \frac{\text{Utilization Energy}}{\text{Theoretical Energy}}
\]

\[= \frac{1730.3}{1732.3}\]

\[= 99.88\%

<table>
<thead>
<tr>
<th>Theoretical Energy of the PV Module</th>
<th>1732.3Wh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization Energy of PV Module</td>
<td>1730.3Wh</td>
</tr>
<tr>
<td>Energy Utilization Efficiency of PV Module using Input Sensing using P&amp;O MPPT</td>
<td>99.88%</td>
</tr>
</tbody>
</table>

### 9.2.2 Water Pumped Per Day

The total water pumped by the DC motor pump in a day (12 hrs.) can be calculated by the simulation curve (Figure 9.1e).

\[
\text{Total Volume of Water Pumped in a day (12 hrs)}
\]

\[= 0.5 \times 12.98 \times 0.9328 \times 60 + 11.0672 \times 12.98 \times 60\]

\[= 363.23 + 8619.14\]

\[= 8982.37\text{litre}\]
Please refer Appendix 1.10 for this MATLAB program

9.3 SIMULATION CURVES OF INCREMENT CONDUCTANCE ALGORITHM USING INPUT SENSING DIRECT CONTROL METHOD WITH CUK CONVERTER AND DC MOTOR PUMP

In this simulation system, the PV module BP SX 150S consists with the ideal (loss-less) CUK converter, the MPPT control, and a DC motor pump. This input sensing direct control method employs the Increment Conductance algorithm to locate the MPP. The various simulation results of using Increment Conductance MPPT with input sensing direct control method are given in Figure 9.2.
(b) Input Sensing Direct Control Method using Increment Conductance Algorithm

- Module Voltage (V)
- Module Current (A)

(c) Input Sensing Direct Control Method using Increment Conductance Algorithm

- Duty Cycle
- Output Power of Converter (W)
(d) Input Sensing Direct Control Method using Increment Conductance Algorithm

Output Voltage of Converter (V)

Output Current of Converter (A)

(e) Input Sensing Direct Control Method using Increment Conductance Algorithm

Flow Rate (L/min)

Time (Hour)
(f) Input Sensing Direct Control Method using Increment Conductance Algorithm

Output Voltage of converter (V)

Rload of DC Motor Pump

(g) Input Sensing Direct Control Method using Increment Conductance Algorithm

Output Power of Converter
Module Power
Figure 9.2: Simulation results of input sensing direct control method using Increment Conductance algorithm.

The irradiance is increased linearly from 200W/m² to 1000W/m² with the same rate of 0.3W/m² per sample. Figures 9.2(a) & 9.2(b) show that the traces of operating points are staying close to the MPPs throughout the simulation. Figure 9.2(c) shows the relationship between the output power of converter and its duty cycle. The output power of converter is increasing with duty cycle up to D < 0.5. Figure 9.2(d) shows the current and voltage relationship of converter output. It shows that the output current rises rapidly with increasing voltage until the current is sufficient to create enough torque to start the motor. Once it starts to run, the back emf takes effect and drops the current, therefore the current rises slowly with increasing voltage. Figure 9.2(e) shows the curve of flow rate of pump vs. time. In the starting the flow rate pump increases with time but after full radiation (1000W/m²), approximately after one hour the flow rate of pump is constant. Figure 9.2(f) shows the curve of load of DC motor pump vs. output voltage of converter. It is shown that the RLoad curve is nonlinear and increases with increasing
converter voltage. Figure 9.2(g) shows the two curves, one curve shows the extracted power or tracking power from the theoretical power of the PV module, and another curve shows the output power of converter. It is seen from both curve that how the total extracted power is transferred to the load by the converter. Figure 9.2(h) shows the power v/s. time curves; one curve is the output power of convert with respect to time while another curve is the input power of converter with respect to time. Both curves are overlap to each other because in the system CUK converter is considers as idle (loss less), so the input power is completely transferred to the load by the converter.

9.3.1 Energy Utilization Efficiency of PV Module

Here in this section, The DC motor pump is coupled with the PV module using input sensing Increment Conductance MPPT, so the utilization power of the PV module is the output power of CUK converter (In other words, the power consumed by the DC motor pump). The utilization energy (utilization energy = utilization power × time) of the PV module from the simulation curve (Figure 9.2h) can be calculated as:-

Utilization energy of PV module for a day (12hrs)

\[= 0.5 \times 149.8 \times 0.9808 + 149.8 \times 11.0192\]

\[= 73.46 + 1650.68\]

\[= 1724.14\text{Wh}\]

\[\sim 1730.3\text{Wh (by simulation program)} \quad (9.4)\]

The Theoretical Energy of the PV module = 1732.3Wh

Energy utilization Efficiency of PV module %

\[= \frac{\text{Utilization / Extraction Energy}}{\text{Theoretical Energy}}\]
9.3.2 Water Pumped Per Day

The total water pumped by the DC motor pump in a day (12 hrs.) can be calculated by the simulation curve (Figure 9.2e).

Total Volume of Water Pumped in a day (12 hrs)

\[
= 0.5 \times 12.98 \times 0.9328 \times 60 + 12.98 \times 11.0672 \times 60 \\
= 363.23 \times 8619.14 \\
= 8982.37 \text{ litre}
\]

\( \sim 8998 \text{ litre (by the simulation program) } \) (9.5)

Please refer Appendix 1.11 for this MATLAB program.

9.4 SIMULATION CURVES OF DECREMENT RESISTANCE ALGORITHM USING INPUT SENSING DIRECT CONTROL METHOD WITH CUK CONVERTER AND DC MOTOR PUMP

In this simulation system, the PV module BP SX 150S consists with the ideal (loss-less) CUK converter, the MPPT control, and a DC motor pump. This input sensing direct control method employs the Decrement Resistance algorithm to locate the MPP. The various simulation results of using
Decrement Resistance MPPT with input sensing direct control method are given in Figure 9.3.
(c) Input Sensing Direct Control Method using Decrement Resistance Algorithm

Output Power of Converter (W)

Duty Cycle

Output Voltage of Converter (V)
Output Current of Converter (A)
(e) Input Sensing Direct Control Method using Decrement Resistance Algorithm

(f) Input Sensing Direct Control Method using Decrement Resistance Algorithm
Figure 9.3: Simulation results of input sensing direct control method using Decrement Resistance algorithm.
The irradiance is increased linearly from 200W/m² to 1000W/m² with the same rate of 0.3W/m² per sample. Figures 9.3(a) & 9.3(b) show that the traces of operating points are staying close to the MPPs throughout the simulation. Figure 9.3(c) shows the relationship between the output power of converter and its duty cycle. The output power of converter is increasing with duty cycle up to D < 0.5. Figure 9.3(d) shows the current and voltage relationship of converter output. It shows that the output current rises rapidly with increasing voltage until the current is sufficient to create enough torque to start the motor. Once it starts to run, the back emf takes effect and drops the current, therefore the current rises slowly with increasing voltage. Figure 9.3(e) shows the curve of flow rate of pump vs. time. In the starting the flow rate pump increases with time but after full radiation (1000W/m²), approximately after one hour the flow rate of pump is constant. Figure 9.3(f) shows the curve of load of DC motor pump vs. output voltage of converter. It is shown that the R_load curve is nonlinear and increases with increasing converter voltage. Figure 9.3(g) shows the two curves; one curve shows the extracted power or tracking power from the theoretical power of the PV module, and another curve shows the output power of converter. It is seen from both curve that how the total extracted power is transferred to the load by the converter. Figure 9.3(h) shows the power v/s. time curve; one curve is the output power of convert with respect to time while another curve is the input power of converter with respect to time. Both curves are overlap to each other because in the system CUK converter is considers as idle (loss less), so the input power is completely transferred to the load by the converter.

9.4.1 Energy Utilization Efficiency of PV Module

Energy utilization efficiency is the ratio of utilization energy of PV module to the theoretical energy (total maximum points energy) of the PV module. Here in this section, The DC motor pump is coupled with the PV module using input sensing Decrement Resistance MPPT, so the utilization
power of the PV module is the output power of CUK converter (in other words, the power consumed by the DC motor pump). The utilization energy (utilization energy = utilization power × time) of the PV module from the simulation curve (Figure 9.3h) can be calculated as:

\[
\text{Utilization energy of PV module for a day (12 hrs)} = 0.5 \times 149.8 \times 0.9539 + 149.8 \times 11.0461
\]
\[
= 71.45 + 1654.71
\]
\[
= 1726.2\text{Wh}
\]
\[
\sim 1730.3\text{Wh (by simulation program)} 
\]
\[
(9.6)
\]

The Theoretical Energy of the PV module = 1732.3Wh

Energy utilization efficiency of the PV module %

\[
= \frac{\text{Utilization Energy}}{\text{Theoretical Energy}}
\]
\[
= \frac{1730.3}{1732.3}
\]
\[
= 99.88\%
\]

<table>
<thead>
<tr>
<th>Theoretical Energy of the PV module</th>
<th>1732.3Wh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization Energy of PV module</td>
<td>1730.3Wh</td>
</tr>
<tr>
<td>Energy Utilization Efficiency of the PV Module using Input Sensing DecRes. MPPT</td>
<td>99.88%</td>
</tr>
</tbody>
</table>

9.4.2 Water Pumped Per Day

The total water pumped by the DC motor pump in a day (12 hrs.) can be calculated by the simulation curve (Figure 9.3e).

Total Volume of Water Pumped in a day (12 hrs)

\[
= 0.5 \times 12.98 \times 0.9006 \times 60 + 12.98 \times 11.0994 \times 60
\]
\[ = 350.69 + 8644.21 \\
= 8994 \text{ litre} \\
\sim 8998 \text{ litre (by the simulation program)} \quad (9.7) \]

Please refer Appendix 1.12 for this MATLAB program.

### 9.5 SIMULATION CURVES OF P&O ALGORITHM USING OUTPUT SENSING DIRECT CONTROL METHOD WITH CUK CONVERTER AND DC MOTOR PUMP

In this simulation system, the PV module BP SX 150S consists with the ideal (loss-less) CUK converter, the MPPT control, and a DC motor pump. This output sensing direct control method employs the P&O algorithm to locate the MPP. The various simulation results of using P&O MPPT with output sensing direct control method are given in Figure 9.4.
(b) Output Sensing Direct Control Method using P&O Algorithm

(c) Output Sensing Direct Control Method using P&O Algorithm
(d) Output Sensing Direct Control Method using P&O Algorithm

Output Voltage of Converter (V)

Output Current of Converter (A)

(e) Output Sensing Direct Control Method using P&O Algorithm

Flow Rate (L/min)

Time (Hour)

X: 0.9539
Y: 12.98
(f) Output Sensing Direct Control Method using P&O Algorithm

(g) Output Sensing Direct Control Method using P&O Algorithm

- **Output Power of Converter**
- **Module Power**
The irradiance is increased linearly from 200W/m$^2$ to 1000W/m$^2$ with the same rate of 0.3W/m$^2$ per sample. Figures 9.4(a) & 9.4(b) show that the traces of operating points are staying close to the MPPs throughout the simulation. Figure 9.4(c) shows the relationship between the output power of converter and its duty cycle. The output power of converter is increasing with duty cycle up to $D < 0.5$. Figure 9.4(d) shows the current and voltage relationship of converter output. It shows that the output current rises rapidly with increasing voltage until the current is sufficient to create enough torque to start the motor. Once it starts to run, the back emf takes effect and drops the current, therefore the current rises slowly with increasing voltage. Figure 9.4(e) shows the curve of flow rate of pump vs. time. In the starting the flow rate pump increases with time but after full radiation (1000W/m$^2$), approximately after one hour the flow rate of pump is constant. Figure 9.4(f) shows the curve of load of DC motor pump vs. output voltage of converter. It
is shown that the Rload curve is nonlinear and increases with increasing converter voltage. Figure 9.4(g) shows the two curves; one curve shows the extracted power or tracking power from the theoretical power of the PV module, and another curve shows the output power of converter. It is seen from both curve that how the total extracted power is transferred to the load by the converter. Figure 9.4(h) shows the power v/s. time curve; one curve is the output power of convert with respect to time while another curve is the input power of converter with respect to time. Both curves are overlap to each other because in the system CUK converter is considers as idle (loss less), so the input power is completely transferred to the load by the converter.

### 9.5.1 Energy Utilization Efficiency of PV Module

Energy utilization efficiency is the ratio of utilization energy of PV module to the theoretical energy (total maximum points energy) of the PV module. Here in this section, The DC motor pump is coupled with the PV module using output sensing P&O MPPT, so the utilization power of the PV module is the output power of CUK converter (In other words, the power consumed by the DC motor pump). The utilization energy (utilization energy = utilization power × time) of the PV module from the simulation curve (Figure 9.4h) can be calculated as:-

\[
\text{Utilization energy of PV module for a day (12hrs)} = 0.5 \times 149.8 \times 0.9006 + 149.8 \times 11.0994 \\
= 67.45 + 1662.69 \\
= 1730.14\text{Wh} \\
\sim 1730.3\text{Wh (by simulation program)} \quad (9.7)
\]

The Theoretical Energy of the PV module = 1732.3Wh

Energy Utilization Efficiency of the PV module
Chapter–9

144

\[
\text{Utilization Energy} = \frac{\text{Theoretical Energy}}{1730.3} = \frac{1732.3}{1732.3} = 99.88\%
\]

<table>
<thead>
<tr>
<th>Theoretical Energy of the PV Module</th>
<th>1732.3Wh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization Energy of PV Module</td>
<td>1730.3Wh</td>
</tr>
<tr>
<td>Energy Utilization Efficiency of PV module using Output sensing P&amp;O MPPT</td>
<td>99.88%</td>
</tr>
</tbody>
</table>

9.5.2 Water Pumped Per Day

The total water pumped by the DC motor pump in a day (12 hrs.) can be calculated by the simulation curve (Figure 9.4e).

Total Volume of Water Pumped in a day (12 hrs)

\[
= 0.5 \times 12.98 \times 0.9539 \times 60 + 12.98 \times 11.0461 \times 60
\]

\[
= 371.45 + 8602.70
\]

\[
= 8974 \text{ litre}
\]

\[
\sim 8998 \text{ litre (by the simulation program) (9.8)}
\]

Please refer Appendix 1.13 for this MATLAB program.

9.6 ENERGY UTILIZATION EFFICIENCY OF DIRECT CONTROL METHOD USING P&O MPPT WITH VARIABLE RESISTIVE LOAD

The authors have previously investigated this approach to adjust the duty cycle of the MPPT converter and found that it offered significantly better energy utilization efficiencies (up to about 91%) compared to directly connected system [1, 11, 96, 97]. In our case also, the energy utilization
efficiency upto 99.88% has already been explained. According to the maximum power transfer theorem, the maximum power can be transferred or extracted from the maximum output power (Theoretical power) of PV module only when the load resistance is equal to optimal resistance ($R_{opt} = \frac{V_{mp}}{I_{mp}}$) of PV module. In other words, the impedance of load matches with the operating condition of the PV module; in general, this operating point is seldom at the PV module’s MPP, thus it is not producing the maximum power. The block diagram of input sensing direct control method using P&O MPPT with variable resistive load is shown in Figure 9.5. A resistive load has a straight line with a slope of $\frac{1}{R_{load}}$ as shown in Figure 9.6b.

Figure 9.5: Block Diagram of input sensing direct control method using P&O MPPT with variable resistive load.
Figure 9.6: I-V Simulation Curve of PV module on various resistive load.

From the Figure 9.6, the maximum output power of PV module (P_{max}) at maximum power points (MPPs) and output power of PV module (P_a) at load can be found out as shown in table 9.1. The maximum voltage
(Vmp) and maximum current (Imp) of PV module is shown in table 9.2. The utilization efficiency is calculated for different resistive loads as shown in table 9.1.

### Table 9.1: Observation values from simulation Figure 9.6

<table>
<thead>
<tr>
<th>Irradiance (W/m²)</th>
<th>O/P Power of PV Module (Pa)</th>
<th>Max. O/P Power of PV Module (Pmax)</th>
<th>Optimal resistance (Ropt) = Vmp/Imp</th>
<th>Rload</th>
<th>Utilization Efficiency % = $\frac{P_d}{P_{max}} \times 100$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 W/m²</td>
<td>45.10W</td>
<td>150W</td>
<td>7.94Ω</td>
<td>2Ω</td>
<td>30%</td>
</tr>
<tr>
<td>1000 W/m²</td>
<td>149.34W</td>
<td>150W</td>
<td>7.912Ω</td>
<td>7.914Ω</td>
<td>99.56%</td>
</tr>
<tr>
<td>800 W/m²</td>
<td>118.79W</td>
<td>118.8W</td>
<td>9.79Ω</td>
<td>9.8Ω</td>
<td>99.99%</td>
</tr>
<tr>
<td>600 W/m²</td>
<td>87.66W</td>
<td>87.67W</td>
<td>12.869Ω</td>
<td>12.87Ω</td>
<td>99.98%</td>
</tr>
<tr>
<td>400 W/m²</td>
<td>56.87W</td>
<td>56.89W</td>
<td>18.841Ω</td>
<td>18.84Ω</td>
<td>99.96%</td>
</tr>
<tr>
<td>200 W/m²</td>
<td>26.91W</td>
<td>26.92W</td>
<td>35.929Ω</td>
<td>35.92Ω</td>
<td>99.96%</td>
</tr>
<tr>
<td>200 W/m²</td>
<td>23.94W</td>
<td>26.92W</td>
<td>35.92Ω</td>
<td>50Ω</td>
<td>88.93%</td>
</tr>
</tbody>
</table>

### Table 9.2: Observation values from simulation Figure 9.6

<table>
<thead>
<tr>
<th>Irradiance (W/m²)</th>
<th>$V_{mp}$</th>
<th>$I_{mp}$</th>
<th>$P_{max}$</th>
<th>$R_{load}$</th>
<th>$R_{opt}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 W/m²</td>
<td>34.45V</td>
<td>4.354A</td>
<td>150W</td>
<td>2Ω</td>
<td>7.94Ω</td>
</tr>
<tr>
<td>1000 W/m²</td>
<td>34.45V</td>
<td>4.354A</td>
<td>150W</td>
<td>7.914Ω</td>
<td>7.912Ω</td>
</tr>
<tr>
<td>800 W/m²</td>
<td>34.11V</td>
<td>3.483A</td>
<td>118.8W</td>
<td>9.8Ω</td>
<td>9.79Ω</td>
</tr>
<tr>
<td>600 W/m²</td>
<td>33.59V</td>
<td>2.61A</td>
<td>87.67W</td>
<td>12.87Ω</td>
<td>12.869Ω</td>
</tr>
<tr>
<td>400 W/m²</td>
<td>32.74V</td>
<td>1.738A</td>
<td>56.89W</td>
<td>18.84Ω</td>
<td>18.841Ω</td>
</tr>
<tr>
<td>200 W/m²</td>
<td>31.1V</td>
<td>0.866A</td>
<td>26.92W</td>
<td>35.92Ω</td>
<td>35.929Ω</td>
</tr>
<tr>
<td>200 W/m²</td>
<td>31.15V</td>
<td>0.866A</td>
<td>26.92W</td>
<td>50Ω</td>
<td>35.92Ω</td>
</tr>
</tbody>
</table>
It is clear from the above table 9.1 and 9.2 that the MPPs can be achieved when optimal resistance ($R_{opt}$) of PV module matches with load resistance ($R_{load}$) and only in this condition, the maximum output power of PV module can be utilized/extracted by the load (in other words, the maximum output power of PV module can be transferred to the load). For example at irradiance 1000W/m$^2$, the value of $R_{opt}$ is not matching with $R_{load}$ so the utilized/extracted power of PV module by the load (in other words transferred power of PV module to the load) is 45.10W in place of 150W, so the utilization efficiency is 30%. Similarly for another example at irradiance 200W/m$^2$, the value of $R_{opt}$ is not matching with $R_{load}$ so the utilized/extracted power of PV module by the load (in other words transferred power of PV module to the load) is 23.32W in place of 26.94W, so the utilization efficiency is 88.93%. In rest of parameter the $R_{load}$ matches with the optimal resistance of PV module so the utilization efficiency is more than 99.56%.

In general, according to maximum power transfer theorem, when $R_{opt} = R_{load}$. The maximum power transfer take place, and in this case the power ($P_{in}$) consumed by internal resistance (optimal resistance) = power ($P_{load}$) consumed by load resistance

$$P_{in} = P_{load}$$

Hence the energy utilization efficiency in terms of theoretical energy is 99.88%, for better matching of loads.

### 9.7 COMPARATIVE ANALYSIS OF ENERGY UTILIZATION EFFICIENCY AND WATER PUMPED

From the above results, the comparative results are given in the table 9.3.
Table 9.3: Comparative Analysis of Results

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy utilization efficiency of PV module</td>
<td>99.88%</td>
<td>99.88%</td>
<td>99.88%</td>
<td>99.88%</td>
</tr>
<tr>
<td>Total Volume of water pumped in a day (12hr.)</td>
<td>8998L</td>
<td>8998L</td>
<td>8998L</td>
<td>8998L</td>
</tr>
</tbody>
</table>

From the table 9.1, the energy utilization efficiency of PV module using MPPT for all system is same, similarly the efficiency of PV module in terms of PV capacity and total volume of water pumped in a day.

9.8 COMPARATIVE ANALYSIS BETWEEN DIRECT–COUPLE AND DIRECT CONTROL METHOD FOR THE APPLICATION OF DC MOTOR PUMP

The comparative results of the system using MPPT and without using MPPT are shown in table 9.4.

Table 9.4: Comparative Results with MPPT and without MPPT

<table>
<thead>
<tr>
<th>Parameters</th>
<th>System using MPPT</th>
<th>System without using MPPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy utilization efficiency of PV module</td>
<td>99.88%</td>
<td>81.49%</td>
</tr>
<tr>
<td>Total Volume of water pumped in a day (12 hr.)</td>
<td>8998L</td>
<td>7340.7L</td>
</tr>
</tbody>
</table>

The results show that MPPT offers significant performance improvement. It enables to pump up to 22.58% more water than the system without MPPT. The utilization efficiency of PV module increases up to 18.39% than the system without MPPT.
9.9 CONCLUSION

The Increment Conductance MPPT and Decrement Resistance MPPT cannot be implemented in the output sensing direct control method while P&O algorithm can be implemented in both direct control methods so that the P&O algorithm is better than other algorithm for this system. In the output sensing direct control method there is need of two sensors, while in the input sensing direct control system there is need of four sensors to sense current and voltage so that the overall cost of the input sensing direct control method is increased. The Energy utilization efficiency of PV module increases up to 18.39% and pump discharge the water up to 22.58% more than the system without MPPT.