Chapter-5

Adaptive Fixed Duty Cycle (AFDC) MPPT Algorithm for Photovoltaic System

5.1 Introduction

Optimum power point tracker (OPPT), despite its drawback of low efficiency, is a technique to achieve delivery of power from array to the load. It is need to improve the PV system efficiency. All the MPPT techniques, heather to discuss till now may not work well due to environmental condition, sudden change of reference voltage or current threshold. The proposed AFDC MPPT method surpasses these drawbacks by quick reaction to this operating point. The effectiveness of proposed algorithm in terms of steady-state performance and improved tracking efficiency are discussed in this chapter.

5.2 Adaptive Fixed Duty Cycle (AFDC) Method

The AFDC control algorithm uses existing inputs of VSPV MPPT algorithms such as differential power (dP) and differential voltage (dV). The proposed algorithm is fixed perturbations steps depending on the nearness of PV operating voltage with the maximum power point voltage. Even though, it claims to have quick convergence during rapid changes in irradiance and load. Moreover, the proposed algorithm to restore comparing and switching methods with ADFC approach, as shown in Fig. 5.1.

5.3 Model of AFDC Algorithm

The output power of the PV array depends upon the solar irradiance and cell temperature. The output power of PV module is given to the grid through the DC-DC
boost converter and DC-AC converter (inverter). The PV output voltage and current is given to AFDC MPPT controller as an input. The AFDC MPPT controller generates duty ratio based on the fixed step-size perturb. In this method, the duty cycle is varied accordingly to perturbation voltage and operating point oscillates around the MPPs. By changing duty ratio, it can match the characteristic impedance of the PV array to the load impedance. Therefore, it quickly transfers the maximum power to the load.

Fig 5.1: Block diagram of Single Phase Grid Connected PV System with AFDC MPPT Technique.

5.4 AFDC MPPT Algorithm

Fig 6.2 shows the association of ‘P’ and ‘D’ curve in the photovoltaic system with boost converter as power conditioner. Where, ‘P’ is represents the photovoltaic output power and ‘D’ is the duty cycle of DC-DC boost converter.
\[ d(k) = d(k-1) \pm \frac{dP/dD}{P/D} \]  

(5.1)

If \( dP/dD > 0 \) be able to access maximum power point, then the equation (5.1) as modified as

\[ d(k) = d(k-1) + \frac{dP/dD}{P/D} \]

(5.2)

Similarly, for \( dP/dD < 0 \), then the expression is

\[ d(k) = d(k-1) - \frac{dP/dD}{P/D} \]

(5.3)

Fig. 5.2 Relationship of P and D.
The operation of $P-D$ curve start with left area, if $dP/dD>0$ be capable of access maximum power point (MPP). However, the actual operating point is in the right-hand area, to keep $dP/dD<0$ to reach maximum power delivery. When the tracking system of $dP/dD=0$, then, the power reaches maximum point. The algorithm steps are

**Step 1:** Start

**Step 2:** Initialize the value of duty ratio between 0 and 1.

**Step 3:** Measure the values of photovoltaic array voltage and current at $k^{th}$ and $k-1^{th}$ instants and compare powers at $k$th and $k$-1th instants.

**Step 4:** If $dP > 0$, slope = 1 and duty cycle is increased by $D + c \times$ slope.

**Step 5:** If $dP < 0$, slope = -1 and duty cycle is decreases by $D + c \times$ slope.

**Step 6:** Save present power as previous power ($k$-1) value.

**Step 7:** Go to Step 3 and repeat the above steps until reaching the Maximum power point.

**Step 8:** Stop.

### 5.5 Flowchart of AFDC MPPT Algorithm

The algorithm compares the present power with the previous one and selects the best among them until the required MPPs is reached. The control algorithm flowchart is shown in Fig. 5.3.
Fig 5.3 Flowchart of AFDC MPPT Technique
5.6 Results and Discussion

5.6.1 Variation of irradiance

To show the effectiveness of proposed MPPT algorithm based PV system, the PV module considered for simulation is 100 Watts multi-crystalline PV panel. The mathematical simulation has been carried out by using MATLAB/Simulink.

Fig 5.4. AFDC: Waveforms of PV Output (a) Voltage (b) Current (c) Power with Irradiance is 1000 W/m² at Temperature is 25 °C.
Fig 5.5. AFDC: Waveforms of PV Output (a) Voltage (b) Current (c) Power with Irradiance is 200 W/m² at Temperature is 25 °C.
Fig 5.6. AFDC: Waveforms of PV Output (a) Voltage (b) Current (c) Power with Irradiance is 1000 W/m² at Temperature is 55 °C.
Fig 5.7. AFDC: Waveforms of PV Output (a) Voltage (b) Current (c) Power with Different Irradiance at Fixed Temperature is 25 °C.
The Simulation parameters and specifications of PV module and boost converter used in this thesis are given in Appendix. From Fig.6.4, it is observed that the performance of the PV output voltage (18.93V), current (4.592A) and power (86.94W) with array irradiance is 1000 W/m\(^2\) at cell temperature is 25\(^\circ\)C. Similarly, from the Fig 6.5, it is observed that the performance of output power and voltage of PV system attains oscillation is significantly more due to low irradiance is 200W/m\(^2\).

Simulation results show the performance of the PV system. Fig.5.6 shows the response of PV output voltage, current and power with irradiance is 1000 W/m\(^2\) at cell temperature is 55\(^\circ\)C. It is clear that, the output power of the PV system is little bit reduced as compared to cell temperature of 25\(^\circ\)C.

Waveforms obtained from the simulation are shown in Fig.5.7. The individual response of output voltage, current and power is varied with varying different irradiance values of 400 W/m\(^2\), 1000W/m\(^2\) and 800W/m\(^2\) at constant cell temperature is 25\(^\circ\)C. It is clear that, when the PV system operated with low irradiance is 400 W/m\(^2\), the corresponding PV output power is significantly less (12.91W). Similarly, when the PV system operated with high irradiance is 1000 W/m\(^2\), the corresponding PV output power is significantly more (86.29W). Moreover, the tracking efficiency of PV system with proposed MPPT algorithm is 86.29%, respectively.

Fig 5.8 shows that, particularly when the solar irradiances is operating at low values, adaptive fixed duty cycle algorithm reaches oscillations is more in PV power output of the PV system. But, when operating at moderate/high values of irradiances, the proposed AFDC control algorithm gives optimal performance in PV output power.

The numerical analytic version can be found from Table 5.1, that the output power of the PV system is 86.29 W during the solar irradiance is 1000 W/m\(^2\) at cell temperature is 25\(^\circ\)C. From Table 5.1 it is observed that, when the cell temperature increases the effectiveness of photovoltaic output power is decreased. Similarly, the temperature increases the effectiveness of photovoltaic output voltage is decreased.
Whereas, the output current of the photovoltaic system is increased by increases in temperature. The same is observed from Table 5.1.

**Fig 5.8.** AFDC: Simulated Waveforms of PV Output Voltage, Current and Power with Different Irradiance at Fixed Temperature is 25 °C.

**Table 5.1**

AFDC: Evaluation PV Output Voltage, Current and Power with different Temperature at Constant Irradiance condition

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Irradiance (W/m²)</th>
<th>AFDC MPPT Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PV Output Voltage ($V_{mp}$)</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>18.97</td>
</tr>
<tr>
<td>35</td>
<td>1000</td>
<td>17.63</td>
</tr>
<tr>
<td>45</td>
<td></td>
<td>16.21</td>
</tr>
<tr>
<td>55</td>
<td></td>
<td>15.45</td>
</tr>
</tbody>
</table>
Table 5.2
AFDC: Evaluation PV Output Voltage, Current and Power with different Irradiance at Constant Temperature condition

<table>
<thead>
<tr>
<th>Irradiance (W/m²)</th>
<th>Temperature (°C)</th>
<th>AFDC MPPT Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PV Output Voltage (V_{mp})</td>
</tr>
<tr>
<td>1000</td>
<td>25°C</td>
<td>18.97</td>
</tr>
<tr>
<td>800</td>
<td></td>
<td>17.70</td>
</tr>
<tr>
<td>600</td>
<td></td>
<td>15.18</td>
</tr>
<tr>
<td>400</td>
<td></td>
<td>11.87</td>
</tr>
<tr>
<td>200</td>
<td></td>
<td>9.985</td>
</tr>
</tbody>
</table>

It is clear that, that the output power of the PV system is 86.29 W during the solar irradiance is 1000 W/m² at cell temperature is 25°C. From Table 5.2 it is observed that, when the solar irradiance vary from low to high, the value of photovoltaic output power is varied low to high. Similarly, the effectiveness of photovoltaic output voltage and current is also varied from low to high, respectively.

It is verified that the proposed MPPT algorithm of PV system strategy works well for medium/high irradiance range. Fig.5.9 shows the analytical evaluation of PV output voltage at different irradiance ratings. Fig.5.10 shows the analytical evaluation of PV output current at different irradiance ratings. Similarly, Fig.5.11 shows the analytical evaluation of PV output power at different irradiance ratings.
Fig 5.9. Analytical evaluation of PV Output Voltage with Different Irradiances.

Fig 5.10. Analytical evaluation of PV Output Current with Different Irradiances.
Fig 5.11. Analytical evaluation of PV Output Power with Different Irradiances.

Fig 5.12. Analytical evaluation of PV Output Power vs Irradiances with Various Proposed Technique.
Based on the above tabulated numerical analysis, it is clearly noticed that AFDC method performs better than previous methods. From Fig 5.12, compared to the previous methods, AFDC MPPT method is proved to be the best, as it minimises the oscillations and increases the tracking efficiency. It is released in Table 5.3.

From Table 5.5, it gives that the power response of the PVS arrangement in terms of settling time at high/low irradiance (1000/200) W/m² of AFDC control is settled very quick (i.e. 0.01/0.006 sec) as compare to VSPV MPPT control.

Table 5.3

Comparative analysis of Proposed MPPT Techniques

<table>
<thead>
<tr>
<th>Irradiance (w/m²)</th>
<th>Temperature (°C)</th>
<th>Variable Step-size Perturb Voltage MPPT Technique</th>
<th>Proposed Adaptive Fixed Duty Cycle MPPT Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>V_{mp} (V)</td>
<td>I_{mp} (A)</td>
</tr>
<tr>
<td>1000</td>
<td>25</td>
<td>16.40</td>
<td>5.076</td>
</tr>
<tr>
<td>800</td>
<td></td>
<td>15.70</td>
<td>4.233</td>
</tr>
<tr>
<td>600</td>
<td></td>
<td>15.01</td>
<td>3.413</td>
</tr>
<tr>
<td>400</td>
<td></td>
<td>14.60</td>
<td>2.062</td>
</tr>
<tr>
<td>200</td>
<td></td>
<td>13.10</td>
<td>0.947</td>
</tr>
</tbody>
</table>

Table 5.4

Performance evaluation of Tracking Efficiency (%)
Table 5.5
Analysis of Time Response

<table>
<thead>
<tr>
<th>Response</th>
<th>Irradiance (W/m²)</th>
<th>MPPT Control Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>VSPV</td>
</tr>
<tr>
<td>Settling Time</td>
<td>1000 (High)</td>
<td>0.15</td>
</tr>
<tr>
<td>(in sec)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 (Low)</td>
<td>0.25</td>
<td>0.006</td>
</tr>
</tbody>
</table>

5.6.2 Variation of Load

Fig. 5.13 shows the ampere-volts curve of PVS with the variation in irradiances. An operating load line produced can be forced on ampere-volts curve when the PVS supplies power to the load.

\[ V_{in} = \frac{1}{1 - D} V_c \]  

(5.4)
\[ I_{in} = \frac{1}{1 - D} I_o \]  \hspace{1cm} (5.5)

and

\[ R_{in} = \frac{1}{1 - D} R \]  \hspace{1cm} (5.6)

The relationships of the voltage and current of the DC-DC boost converter between the input and output sides are shown in (5.4) and (5.5). Equation (5.6) shows that the duty cycle can be regulated to impose the input resistance of the converter to be varied until the load line cuts though the I-V curve at MPP.

![Graph showing tracking efficiency vs load resistance](image)

**Fig 5.14 Proposed AFDC MPPT Algorithm: Analytical evaluation of Tracking efficiency at various Load Resistance.**

Fig 5.14 illustrates the investigative representation of tracking efficiency versus load resistance (ohms). From this analysis, when the load resistance is increased then the tracking efficiency is decayed parabolically, according to the maximum power theorem. It is clearly observed in Table 5.6.
Fig 5.15 VSPV and AFDC MPPT Algorithms: Analytical evaluation of Tracking efficiency at various Load Resistance.

Table 5.6
AFDC: Evaluation of PV Output Voltage, Current, Power and Tracking efficiency at different Load Resistance.

<table>
<thead>
<tr>
<th>Load Resistance (Ohms)</th>
<th>Proposed AFDC MPPT Algorithm</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$I_{PV}$</td>
<td>$V_{PV}$</td>
</tr>
<tr>
<td>9</td>
<td>4.548</td>
<td>18.97</td>
</tr>
<tr>
<td>12</td>
<td>4.21</td>
<td>18.16</td>
</tr>
<tr>
<td>15</td>
<td>3.23</td>
<td>19.81</td>
</tr>
<tr>
<td>20</td>
<td>2.66</td>
<td>19.88</td>
</tr>
<tr>
<td>50</td>
<td>1.149</td>
<td>20.10</td>
</tr>
<tr>
<td>75</td>
<td>0.85</td>
<td>20.24</td>
</tr>
<tr>
<td>150</td>
<td>0.342</td>
<td>20.51</td>
</tr>
<tr>
<td>200</td>
<td>0.273</td>
<td>20.59</td>
</tr>
</tbody>
</table>
Fig. 5.15 shows the recital of VSPV and proposed MPPT algorithm at various load conditions. It is clear that from Table 5.6, if the duty cycle is constant, the variation of load resistance is increase (decrease) the voltage and decrease (increase) in current of the photovoltaic system. Though, variation in the voltage and current are always in the opposite direction under load variation.

5.6.3 Variation of Duty cycle

The variation of the duty cycle changes input voltage of the DC-DC boost converter and therefore the photovoltaic module operating point responds rapidly and operates near to the new MPP whenever there is variation in solar irradiance.

![Graph showing the relationship between Tracking Efficiency and Duty Cycle](image)

**Fig 5.16 AFDC: Simulated relationship of Tracking efficiency vs Duty cycle**

Fig 5.16 shows the closed loop response for 40% to 60% variation in duty cycle. The results portray that the controller objective are realized for limiting the
speed and tracking efficiency deviations in acceptable values. The verification of maximum power point power as observe 86.29W. It is released in Table 5.7.

Table 5.7
AFDC: Eavulation PV Output Voltage, Current and Power with different duty cycle

<table>
<thead>
<tr>
<th>Duty cycle (%)</th>
<th>Proposed MPPT Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vpv</td>
</tr>
<tr>
<td>40</td>
<td>19.96</td>
</tr>
<tr>
<td>50</td>
<td>19.57</td>
</tr>
<tr>
<td>60</td>
<td>18.97</td>
</tr>
<tr>
<td>70</td>
<td>14.01</td>
</tr>
<tr>
<td>80</td>
<td>12.35</td>
</tr>
</tbody>
</table>

5.6.4 Results of boost converter

To validate the performance of the proposed system, simulations are performed with MATLAB/Simulink. On the DC side, the photovoltaic maximum power is successfully injected into the DC-DC boost converter with high tracking efficiency. The DC-DC boost converter of output current (2.14A), voltage (38V) and power (81.32W) are shown in Fig.2.21.
Fig. 5.17 Proposed AFDC Algorithm: Simulated waveforms of Boost converter output (a) Current, (b) Voltage and (c) Power.
5.6.5 H-bridge inverter and utility grid

The power stage of the system proposed is illustrated in Fig. 5.1. Power flows from the photovoltaic module to the grid through the single phase H-bridge inverter, which operates as a boost converter in each half line cycle, provided that a suitable SPWM control of the four switches is operated. The steady-state response of grid voltage waveform is depicted in Fig. 5.18. From Fig. 5.18 it is observed that the frequency of grid voltage is maintained at the fundamental frequency (i.e. 50 Hz).

![Fig. 5.18 Steady-state grid voltage](image)

5.7 Conclusions

The proposed adaptive fixed duty cycle MPPT algorithm is tested on a closed loop system. The proposed algorithm reduces the oscillation around the MPPs and fast dynamic response involved in the all previous MPPT control techniques. It can be conclude that, the proposed MPPT control algorithm gives improved performance as compared to all other control techniques. Hence, to improve the performance of PV system, in terms of increased tracking efficiency and reduced oscillation around MPPs in the output of the PV power during low/medium/high temperature and irradiance regions, AFDC MPPT suits well.