



# DEVELOPMENT OF VHDL CODING FOR MAXIMUM POWER POINT TRACKING ALGORITHMS

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## Abstract

In this paper, the Maximum Power Point Tracking algorithms are designed using Very High Speed Integrated Circuit Hardware Description Language. The MPPT algorithms like Perturb & Observe Method and Incremental & Conductance Method are designed and compared with device utilization charts in Xilinx ISE 12.1. With the mathematical equation the PV cell is modeled and simulated in SIMULINK-MATLAB blocks. The simulation tools like ModelSim 5.7g, Xilinx ISE 12.1 and SIMULINK-MATLAB are used. The results prove that the MPPT algorithms could be easily implemented using Field Programmable Gate Array in Real Time.

**Keywords:** PV cell model, Perturb & Observe MPPT algorithm, Incremental Conductance MPPT algorithm, VHDL coding

## I. INTRODUCTION

The solar energy is an easily available natural resource on Earth. The invention of PV cell has given way for utilization of Sun's irradiation by converting it into DC electrical energy. Basically, a PV cell is a PN-junction diode and its mathematical model is a simple diode current equation taken along with parameters like temperature and irradiances. The mathematical model of a PV cell is discussed in the following section. The model of the PV cell is developed using SIMULINK-MATLAB [1][2].

The V and I obtained from the PV cell model need to be evaluated for the point at which maximum power occurs. The MPP is manipulated by the MPPT algorithms. The Perturb and Observe MPPT Method and

Incremental and Conductance MPPT Method are used in this work. The Maximum power is obtained accurately and quickly using P&O method [4]. The P&O is simple in design and operation [5]. The Incremental and Conductance method provides a good tracking efficiency, response is high and well control for the MPPT [3]. VLSI based MPPT algorithm gives a stepwise adaptive search leading to fast convergence and performance [6]. In this paper, the MPPT algorithms are designed and simulated using VHDL coding. The VHDL uses the mixed style of modeling for the MPPT algorithms. The simulation tools like ModelSim and SIMULINK-MATLAB are utilized for evaluation.

## II. MATHEMATICAL PV CELL MODEL

### A. Diode current equation

The mathematical model of the PV cell is governed by the following equation

The Module Photo Current Equation is given by

$$I_{ph} = [I_{sc} + k_1(T - 298)] * A / 1000$$

The Reverse Saturation Current Equation is as below

$$I_{rs} = I_{sc} / \left[ \exp\left(\frac{qV_{oc}}{N_s k T}\right) - 1 \right]$$

The Saturation Current " $I_r$ " varies with cell temperature

$$I_r = I_{rs} \left[ \frac{T}{T_r} \right] \exp \left[ \frac{q * E_{gs}}{Bk} \left( \frac{1}{T_r} - \frac{1}{T} \right) \right]$$

The PV module generates the following PV current represented by " $I_{pv}$ " as given below

$$I_{PV} = N_P \cdot I_{PH} - N_P \cdot I_0 \left[ \exp \left\{ \frac{q \cdot (V_{PV} + I_{PV} R_s)}{N_s A K T} \right\} - 1 \right]$$

The above equations are configured into blocks using SIMULINK-MATLAB blockset .

### III. MPPT ALGORITHMS

The Maximum Power Point Tracking algorithm is of two types. They are

- i) Perturb and Observe Algorithm.
- ii) Incremental Conductance Algorithm.

#### A. Perturb and Observe Algorithm

The P&O algorithm measures the Voltage and Current from the PV module. The measured values of Voltage and Current are utilized for the Power Calculation. These measurements and calculation are obtained for several iterations. Each iteration, the values of  $V_T$  and  $P_T$  are compared with the previous values of  $V_{T-1}$  and  $P_{T-1}$ . The condition for Maximum Power Point (MPP) is as follows

- i. If the present value of  $P_T > P_{T-1}$  and  $V_T > V_{T-1}$  then the reference value  $V_{REF}$  is incremented by 1 bit.
- ii. If the present value of  $P_T > P_{T-1}$  and  $V_T < V_{T-1}$  then the reference value  $V_{REF}$  is decremented by 1 bit.
- iii. If the present value of  $P_T < P_{T-1}$  and  $V_T < V_{T-1}$  then the reference value  $V_{REF}$  is incremented by 1 bit.
- iv. If the present value of  $P_T < P_{T-1}$  and  $V_T > V_{T-1}$  then the reference value  $V_{REF}$  is decremented by 1 bit.

#### B. Incremental Conductance Algorithm

The I&C algorithm measure the V and I values for every iteration. The difference in the present value and previous value of Voltage and Current are defined as  $dV$  and  $dI$  respectively.

$$dI = I - I_0$$

$$dV = V - V_0$$

The ratio of  $\frac{dI}{dV} = -\frac{I}{V}$  is utilized for the evaluation of MPP. The condition for MPP in I & C algorithm is as follows

- i. If  $\frac{dI}{dV} > -\frac{I}{V}$  and  $\frac{dI}{dV} < -\frac{I}{V}$ , then the reference value  $V_{REF}$  is decremented by 1 bit.
- ii. If  $\frac{dI}{dV} < -\frac{I}{V}$  and  $\frac{dI}{dV} > -\frac{I}{V}$ , then the reference value  $V_{REF}$  is incremented by 1 bit.

iii. If  $dV = 0$ ,  $dI \neq 0$  and  $dI > 0$  then the reference value  $V_{REF}$  is decremented by 1 bit.

iv. If  $dV = 0$ ,  $dI \neq 0$  and  $dI < 0$  then the reference value  $V_{REF}$  is incremented by 1 bit.

v. If  $dV = 0$  and  $dI = 0$ , then the values of present and previous of V and I are same. If  $dV \neq 0$  and  $\frac{dI}{dV} = -\frac{I}{V}$ , then the values of present and previous of V and I are same.

#### C. VHDL Code for MPPT algorithm

The VHDL coding for the MPPT method involves the acquiring the PV model. The PV cell module is interlinked with the VHDL code by using Xilinx Blockset Tools. The Concept of converting the VHDL code into block is made possible by using the Black box option available in the SIMULINK-MATLAB XILINX BLOCKSET tools. In order to synchronise the VHDL code with the PV SIMULINK model, the frequency of the MPPT box is adjusted in the System Generator Block. This system generator block is mandatory for all .mdl files which utilizes the interlinking of SIMULINK-MATLAB blocks with VHDL code. All the values of  $P_k$ ,  $V_k$  are declared as Integer types in the VHDL code. The PWM is generated using the following logic as shown below fig.7. The PWM is given as control input for the for the DC-DC buck converter in open loop. The SIMULINK-XILINX BLOCKSET MODEL of the proposed method is shown in Fig.1 The flowchart for the VHDL code implementation of the proposed algorithm is depicted in the Fig.2.

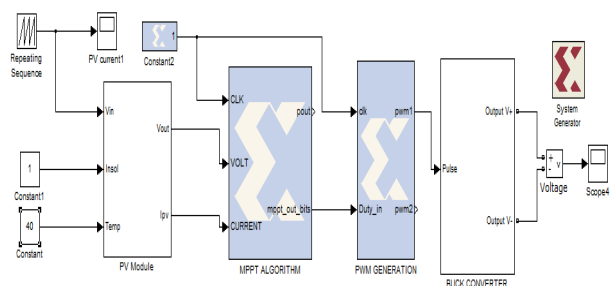


Fig.1 SIMULINK-MATLAB MODEL for the proposed method

IV. UNITS

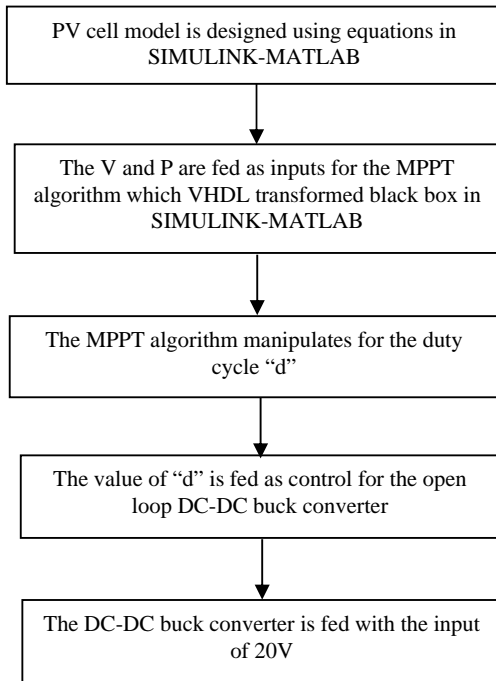


Fig.2 Flowchart of the VHDL code based MPPT algorithm

```

    if rising edge(clk)then
      c<= c+1;
      if c>0 and c < 1000 then
        car <= car+1;
      elsif c>1000 and c < 2000 then
        car <= car-1;
      elsif c>=2000 then
        car <= 0;
        c <= 0;
      end if;

      c1<=car;--(205*car)/256;

      if c1 <= ref then
        pwm1 <='1';
      else
        pwm1 <= '0';
      end if;

      if c1-100 <= ref then
        pwm2 <='0';
      else
        pwm2 <= '1';
      end if;
    end if;
  
```

Fig.3 VHDL CODE for PWM Generation

V. RESULTS AND DISCUSSION

The PV model graph for the PV and VI characteristics are shown in Fig. 4 & 5. The DPWM output for the MPPT algorithm is shown in Fig 6. The Fig.7 shows the open loop response of the DC-DC buck converter with the MPPT algorithm based PWM control. The start-up transient timing analysis for the open loop response is tabulated in the Table I.

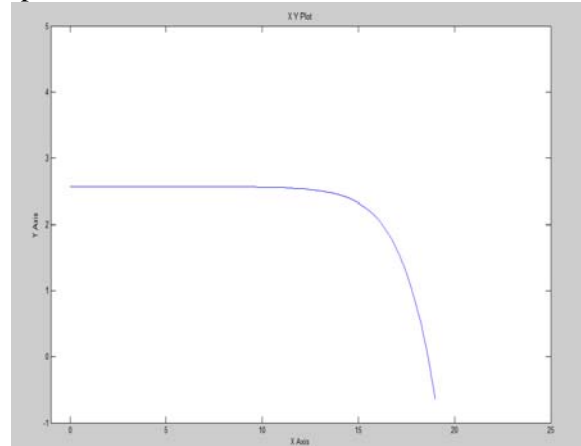


Fig.4 VI characteristics of the PV cell model

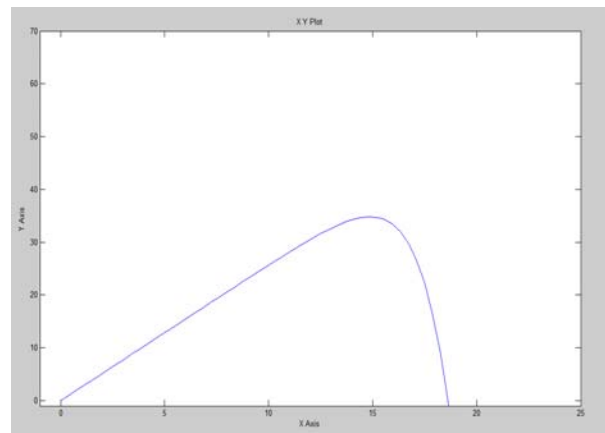


Fig.5 PV characteristics of the PV Cell Model

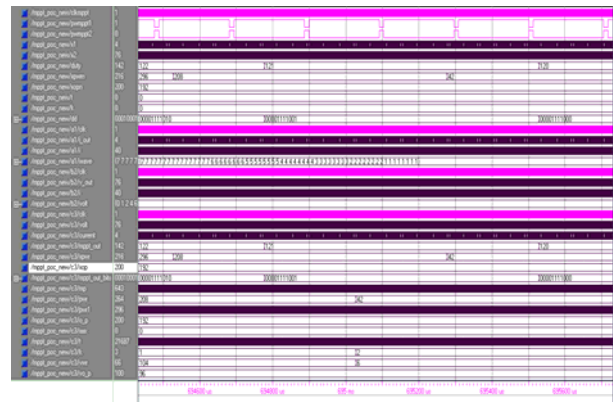


Fig.6 VHDL code based MPPT-PWM control output in Model Sim

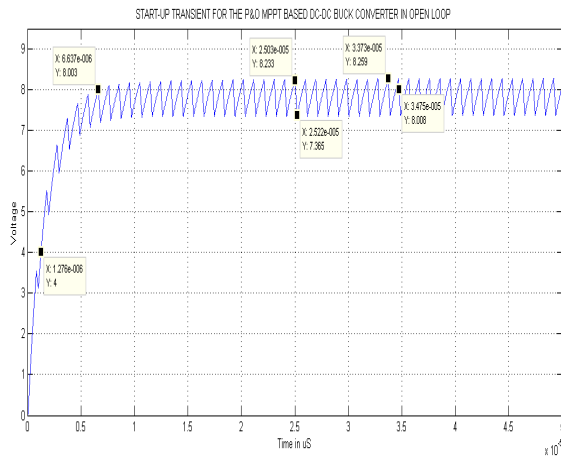


Fig.7 Start-up Transient response of DC-DC buck converter in open loop using MPPT algorithm

Table I Start-up Transient with the Timing parameters for the proposed method

Method	P&O METHOD
Settling Time in $\mu s$ ( $t_s$ )	34.75
Rise Time in $\mu s$ ( $t_r$ )	6.637
Delay Time in $\mu s$ ( $t_d$ )	1.276
Peak Time in $\mu s$ ( $t_p$ )	33.73
Steady State Error ( $e_{ss}$ )	10.57%
Percentage Overshoot (%MP)	0

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