

FPGA-based Implementation of Maximum Power Point Tracking of Solar Cell

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Abstract

This article describes the FPGA based implementation of Maximum Power Point Tracking (MPPT) using Perturbation and Observation (P & O) algorithms for solar cell. This work has been organized in two parts. The complete Maximum Power Point Tracking (MPPT) system model was developed in MATLAB/Simulink environment for functionality verification in the first part. It has been observed from the results which show that maximum power is extracted at the load from PV panel. The second part is to design of P & O algorithm from VHDL code. The designed P & O algorithm was synthesized in Xilinx ISE 14.2 software with small commercial FPGA devices i.e. KINTEX-7 and VIRTEX-5. That designed algorithm was simulated using vector waveform file in FPGA tools. Also, the synthesized results were compared on the basis of area-performance-power obtained through summary of both KINTEX-7 and VIRTEX-5 Xilinx FPGA devices. This work is highly beneficial in real time implementation of algorithm for effective performance.

Key words: PV Cell; Maximum Power Point Tracking (MPPT); DC-DC boost Converter; P & O tracking algorithm; FPGA Xilinx ISE tool

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INTRODUCTION

Renewable energy sources have got great importance to meet the high energy demands. The solar energy is one of the important from the non-renewable energy sources (Goma et al., 2014). DC electricity is generated from the solar energy as it falls on the devices called Photovoltaic (PV) cells. Nowadays, PV systems are considered as the most energy solutions because of the advantages like noiseless, recyclable, distributed throughout the earth and abundant. Unfortunately, these systems have some considerable drawbacks for instance their low conversion efficiency and high installation cost (Luppina et al., 2015). The main problem with the PV systems is the non-linearity. These have nonlinear current-voltage (IV) characteristics which vary with change in temperature and irradiance (W/m²). Thus, output power of the PV panel changes nonlinearly throughout the day (Choudhary et al., 2014). Therefore, it is very essential to operate the PV panel at its maximum possible power point (Sridhar et al., 2012). The technique or algorithm that is used to set the PV panel at its maximum point where it delivers maximum power under different environmental conditions is known as the maximum power point tracking (MPPT) (Ilayachi et al., 2014) which is fully electronic. The complete MPPT system can be shown in Figure 1.

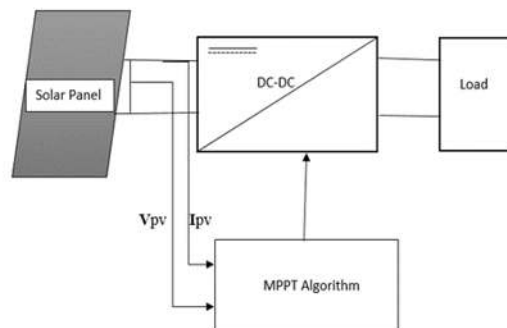


Figure 1: MPPT system Model

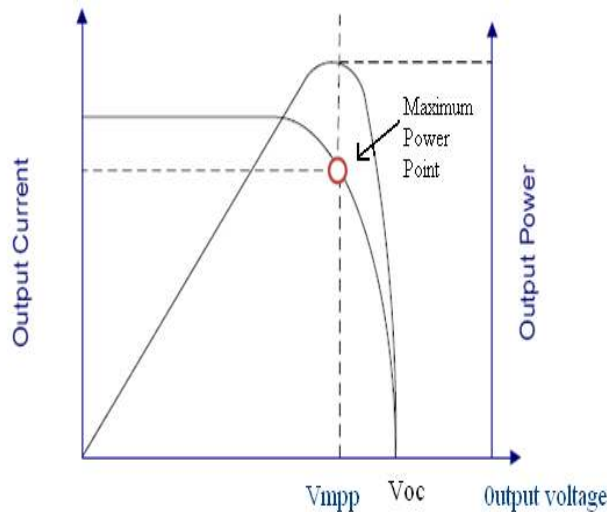


Figure 2: Maximum Power Point Tracking concept

There are many techniques have been discussed in the past literature like Incremental Conductance (IC), Perturb and Observe (P & O), Constant Voltage (Fang et al., 2007), Artificial Neural Network (ANN) (Ravi et al., 2008), Temperature Gradient (TG) (Piegari et al., 2015) and others. Different methods have been used for implementing MPPT algorithms to make MPPT controllers as DSP-based, microcontroller based. Advancement in present day technology paved the way for designers to implement the MPPT controller on programmable IC chips like Field Programmable Gate Array (FPGA).

FPGA has advantages that these are faster than microprocessor or microcontroller due to parallel processing (Y.F Chan et al., 2004). In addition, these have limitless flexible due to their reconfigurable property. These are fit to design the control algorithms however control algorithm designs using DSP's or microcontroller have slow response due to event sequencers or interrupts. Thus, FPGA's are very useful for realizing control designs. FPGAs are programmed through the Hardware Description Languages like VHDL (Very High Speed Integrated Circuit HDL) and Verilog. These have flexibility to be programmed while running process in microseconds. So, this very short period of the time cannot even be sensed by the system that the chip is reprogrammed.

In this paper, P & O algorithm has been developed in FPGA. This research methodology is divided into two parts. The first part includes the design of complete MPPT model in MATLAB/Simulink environment for functionality verification. After that, the second part includes the implementation of P & O algorithm using VHDL/system generator in FPGA and simulation of the design using vector waveform file in FPGA tools. It is also included to analyze the area-performance-power of the system.

System Design in Matlab/simulink

Project development of MPPT system in MATLAB involves the modelling of 50W PV panel from its mathematical equations and the mathematical equations are derived from the PV cell electrical equivalent circuit. Furthermore, DC-DC boost converter has been modelled from its schematic diagram with resistive load connected at the output. The tracking algorithm P & O is designed in Matlab function block. Finally, whole system has been tested for functionality verification. Besides, the VHDL code for the P & O algorithm has been synthesized in Xilinx ISE software for FPGA implementation.

PV Cell Modeling

There are different models of PV cell which are used like single diode, double diode, three diodes model. As a fact above, the one diode model requires only single diode for its construction, two diodes are required for the construction of two diode models and also the three diodes are the requirement of three diodes model. In this project, single diode cell is opted which is constructed from connecting the light generated current source in parallel with the single diode.

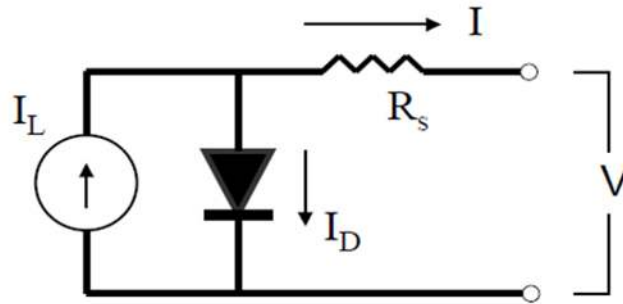


Figure 3: Single Diode Model of PV cell

To design the PV cell model in SIMULINK, the mathematical modelling and the parameters of the PV model are required. Mathematical modelling of the single diode PV cell is given as:

$$I = Np * I_{pv} - Np * I_d * \left\{ e^{\left[\frac{q}{Ns * A * k * T_{ak}} * (V_o + I * R_s) \right]} - 1 \right\} \quad (1)$$

I = Output Current of the PV module

$I_{pv} = I_L$ = PV module light generated current

I_d = Diode saturation Current

Np = No. of cells connected in parallel = 1

R_s = Series resistance of PV module = 0.45 ohm

V_{oc} = Open Circuit Voltage

Ns = No. of cells connected in series = 36

T_{ak} = Operating temperature of PV module in Kelvin

q = Electron charge = $1.6 \times 10^{-19} C$

A = Ideality factor = 1.3

Table 1: PV Panel Parameters at 25° C and $S = 1000 W/m^2$

Attribute	Value
Open Circuit Voltage (V_{oc})	21.8 V
Short Circuit Current (I_{sc})	3.11 A
Power at MPP (P_{mp})	50 W

Above table shows the PV cell parameters and the Simulink model of 50W PV cell can be developed from the characteristics equation as (Figure 4-6).

DC-DC boost converter modeling

To track the maximum operating point of the PV cell for different temperature and solar irradiance which change throughout the whole day, specific circuits have been introduced in the literature.

The more common circuit used for maximum power point is DC-DC converters placed between source which is PV panel and the load. The DC-DC converter is controlled by the proposed tracking technique. In the past, researches have been done by many scholars mainly in two categories on MPPT. The first category is related to the topology optimization of DC-DC converter. In this, there is a focus on methods to get suitable DC-DC converter to track the maximum point of power (R.F Coelho et al., 2009). The second one is related to the tracking technique which is responsible to operate the DC-DC converter properly to track the maximum power point. Thus, it is need to develop an efficient maximum power point tracking system from the suitable

hardware and software. The hardware is the DC-DC converter whereas, the software refers to the tracking algorithm.

The DC-DC boost converter has been used in this research between the PV panel and the load in order to deliver maximum power at the load. Its construction involves the inductor, capacitor, diode and the active switch like MOSFET or IGBT. The converter with MOSFET has been used for this system. The basic schematic diagram of the DC-DC boost converter is shown on Figure 7-8.

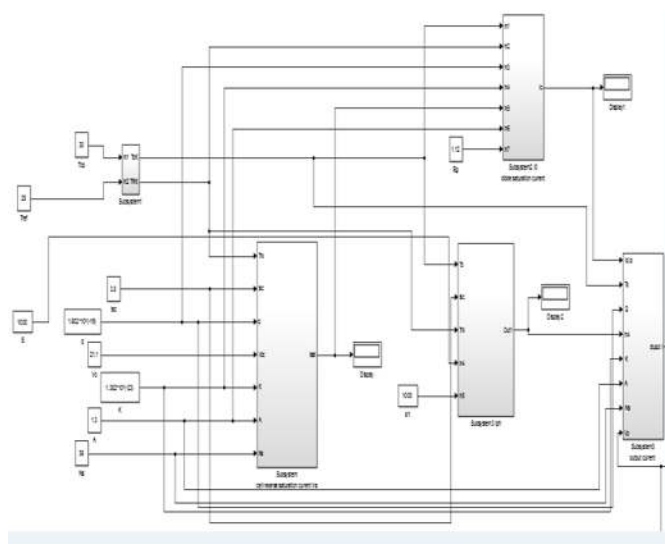


Figure 4: Simulink Model of 50W PV model

PV cell Simulation and Verification

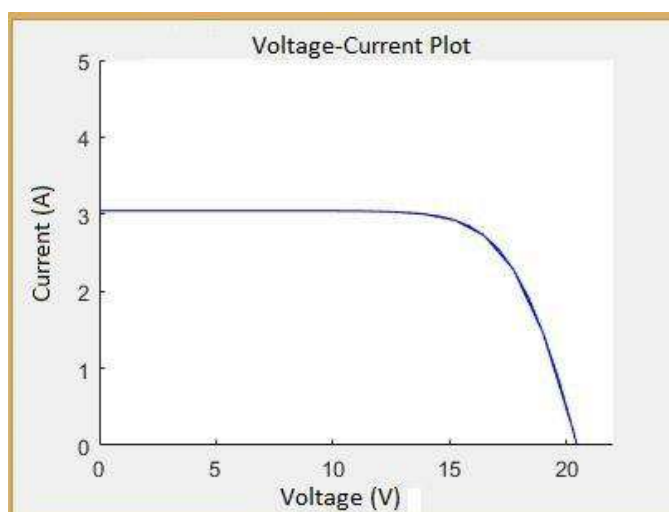


Figure 5: IV curve for 50W PV cell

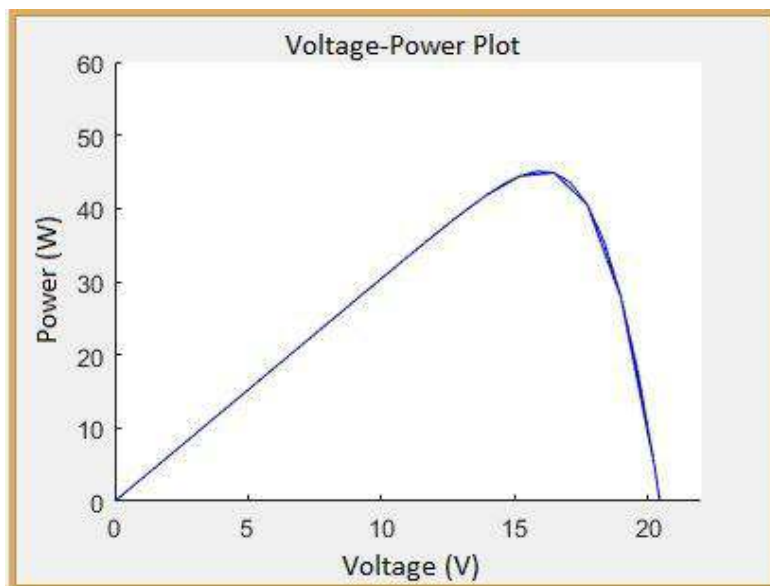


Figure 6: PV curve for 50W PV cell

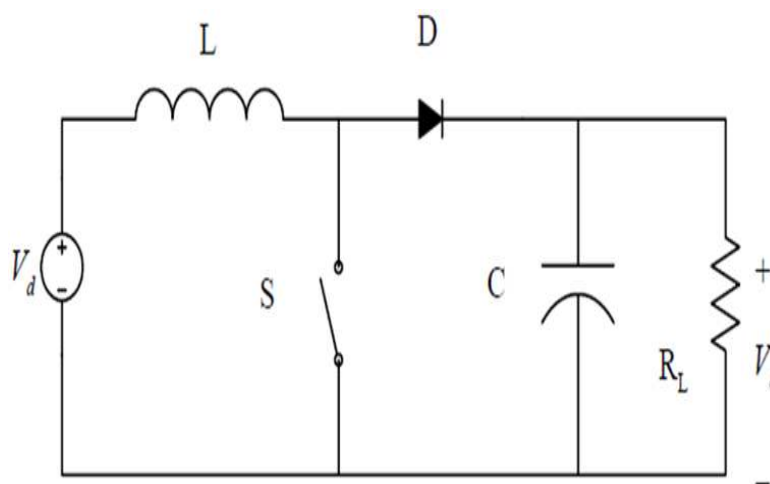


Figure 7: DC-DC boost converter

The above given schematic diagram can be used to develop the Simulink model of the converter in Matlab/Simulink environment. The proposed Simulink model in Matlab will be as:

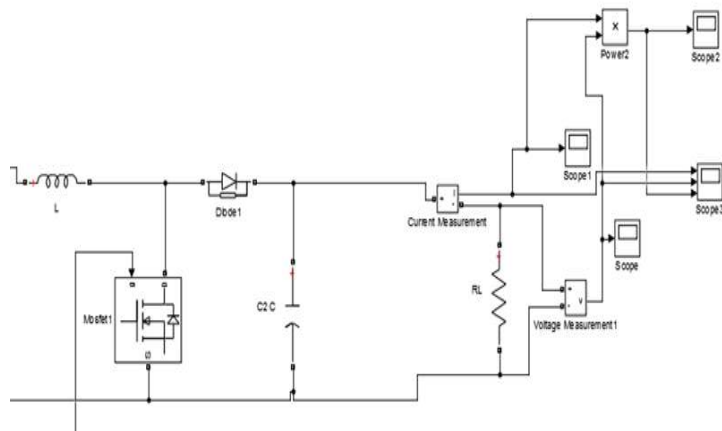


Figure 8: Simulink model of the DC-DC boost converter

Perturb and Observe (P & O) algorithm modeling

P & O is very often used method for the reason that it is easy in implementation and it involves Hill climbing nature therefore, is also called as Hill Climbing method. It requires less number of sensors (Pulkit Singh et al., 2015). In this technique PV cell operating voltage is to be perturbed (increased or decreased) to make the output power maximum. Further, when the voltage from the PV panel is increased and with that power is also increased it shows that point is going towards the MPP. In other case, if the power from PV panel decreases with increase in operating voltage the point must be perturbed in reverse direction (Nicola Femia et al., 2005). Here in this project, MATLAB function block is used to design the P & O algorithm based controller for Maximum Power Point Tracking. The inputs to the controller are current and voltage from the PV panel and output will be the PWM signal. The code can be created by following flow chart of the P & O algorithm.

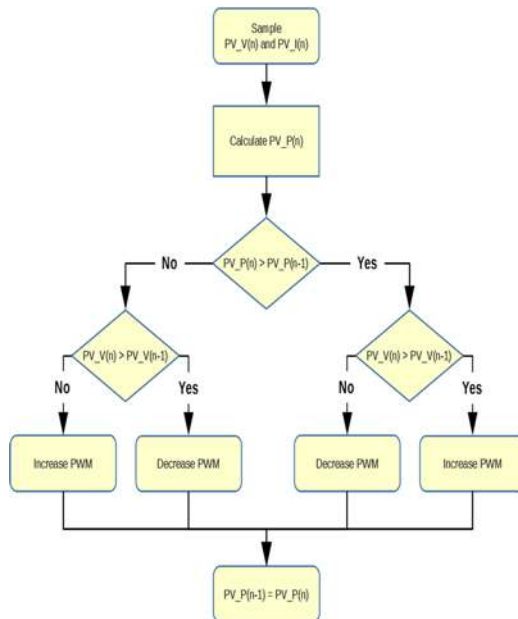


Figure 9: Flow chart of P & O algorithm

Complete MPPT system modelling and its working

The complete MPPT Model is developed as the DC-Dc boost converter is placed in between the PV panel and the load. PV panel outputs current and voltage are sensed by the current and voltage sensors and then current and voltage are fed into the P & O controller. The PWM signal will be the output of that controller and that generated PWM signal will be fed into the MOSFET of the DC-DC boost converter which sets the PV panel to deliver the maximum power at the load.

The complete MPPT model on MATLAB/SIMULINK has been developed as.

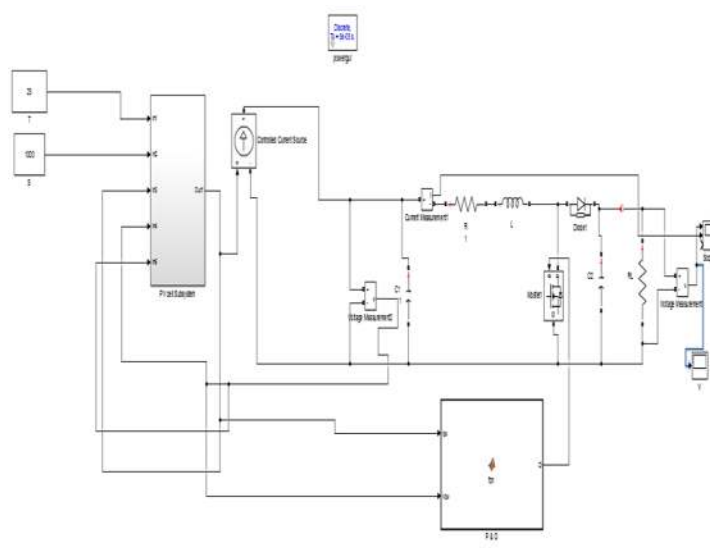


Figure 10. Complete Simulink Model of MPPT system

FPGA IMPLEMENTATION OF P & O ALGORITHM

After the complete model has been modelled on the MATLAB/ Simulink. The P & O algorithm is to be generated in VHDL code. The VHDL code has been synthesized in FPGA and the FPGA will work as MPPT controller. Simply, the design of the algorithm on FPGA include:

- Implement the P & O algorithm using VHDL/system generator in FPGA.
- Simulate the design using vector waveform file in FPGA tools.
- Compute the area-performance and functionality of the design using various small commercial FPGA devices.

In this project, Xilinx ISE tool 14.2 has been selected to design the algorithm. VHDL code for the P & O algorithm has been generated and then it will be synthesized in Xilinx ISE 14.2 software for two Xilinx FPGA devices VIRTEX-5 and KINTEX-7. Both devices will be compared on the basis of performance, power and resource utilization.

RESULTS

The results of this research has been divided into two parts to verify the developed project. The first results include the simulation results in MATLAB/Simulink environment for functionality verification and the second results are the FPGA results when VHDL code of the P & O algorithm has been synthesized in Xilinx ISE 14.2. Further VHDL code has been synthesized for two Xilinx FPGA devices KINTEX-7 and VIRTEX-5. Finally, the vector waveform for the design has been carried out and also the comparison has been made on the basis of area-performance and power for both FPGA Xilinx devices.

MATLAB Simulation results

Complete model when simulated in MATLAB, the simulation results are as:

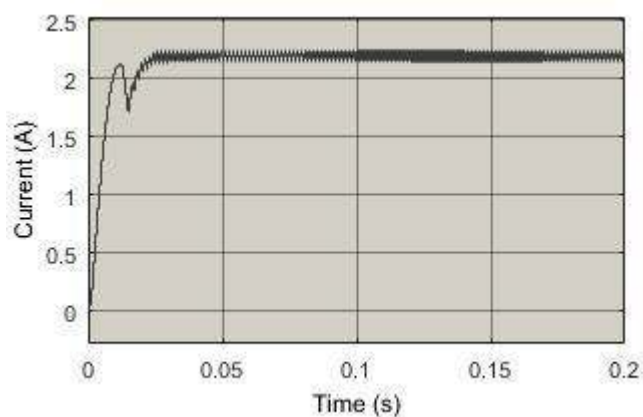


Figure 11. Current (A) at the load

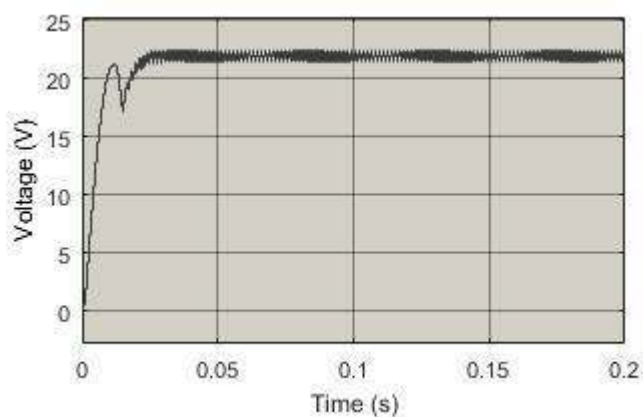


Figure 12. Voltage (V) at the load

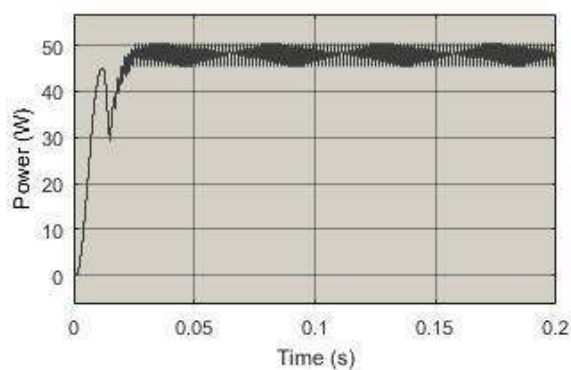


Figure 13. Maximum power (W) delivered at load

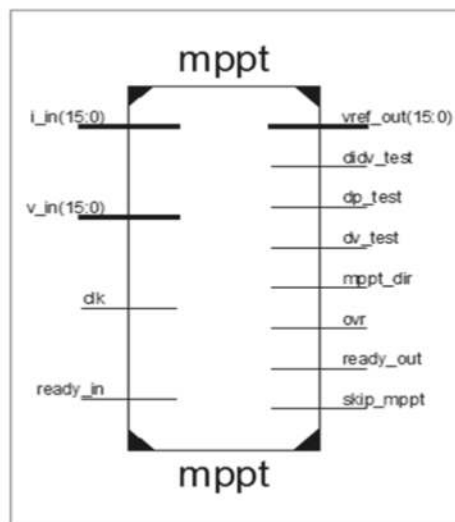


Figure 16: RTL view for the P & O algorithm

RTL is the Register Transfer Level view which describes the pre-optimized design of the synthesized file. It helps the designer to know the issues during the design.

Table 2: FPGA Resource Utilization

Resources	Kintex-7			Virtex-5		
	Used	Available	Utilization (%)	Used	Available	Utilization (%)
No. of Slice LUTs	284	222,600	1	217	28,800	1
No. slice registers	183	445,200	1	195	28,800	1
No. of DSP48A1's/DSP48Es	1	1440	1	1	48	2
Number of Bonded IOBs	57	300	19	57	480	11

Table 3: A summary calculated time delay

Device	Time Delay (ns)
KINTEX7-(XC7K335T)	3.203
VIRTEX5-(XCVLX50T)	4.667

Table 4: Power consumption for both FPGA devices

Power (W)	KINTEX7-(XC7K335T)	VIRTEX5-(XCVLX50T)
STATIC	0.138	0.448
DYNAMIC	0.000	0.004
TOTAL	0.138	0.452

CONCLUSION

It is concluded from the designed MPPT model in MATLAB/SIMULINK environment that maximum power approximately 50W is delivered at the load. Further, VHDL code of P & O algorithms has been tested and synthesized in Xilinx ISE 14.2 software where vector waveform has been carried out. Also, the P & O algorithm has been synthesized for both Xilinx FPGA devices KINTEX7-XC7K335T and VIRTEX5-XC5VLX50T which are compared on the basis of area, performance and power for P & O algorithm.

After analyzing both FPGA devices, the much better choice on the basis of Area-VIRTEX5- XC5VLX50T Performance- KINTEX7-XC7K335T

Power- KINTEX7-XC7K335T

Comparison results show that KINTEX7-XC7K335T is best choice for performance and consuming less power while the VIRTEX5- XC5VLX50T utilizes less resources like number of LUTs, IOB and registers.

Future work of the system includes: This system can also be developed by using buck and boost converter operations in order to achieve the different voltage levels as per our desire. Modifications can be made to set the applications of the project where more PV cells or panels are present.

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