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# Field Programmable Gate Array Chip Design for Hybridized PSO-BFO Based Maximum Power Point Tracker

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**ABSTRACT**

In the recent times, intensive focus has increased in solar photovoltaic (PV) systems, especially in the area of maximum power point tracking (MPPT) devices and inverters. This paper presents an innovative MPPT algorithm to extract maximum power from PV modules by hybridizing fast searching algorithms: particle swarm optimization (PSO) and bacterial foraging optimization algorithm (BFOA). The main advantage of the proposed hybrid technique is reduced steady state oscillations (closely to zero), after the maximum power point (MPP) is tracked. The results confirm the effectiveness of the proposed hybrid technique when compared with PSO and BFOA based MPPT techniques. Tuned parameters with hybrid scheme based controller have been practically tested successfully with the hardware prototype and Xilinx hardware co-simulation also.

***Keywords:*** Photovoltaic(PV) system, Maximum Power Point Tracking (MPPT), Boost Convertor, Particle Swarm Optimization (PSO), Bacterial Foraging Optimization Algorithm (BFOA).

## 1. INTRODUCTION

Renewable energy generation systems are attaining greater attention than before in recent years, as they have demonstrated to be reliable source of energy generation. Among them, the photovoltaic (PV) system is considered to be chief source of renewable energy because of its benefits: least maintenance cost, eco friendly and panels do not require maintenance.The grid-connected type PV systems are commercialized in many countries [1]–[3]. Maximum power point tracker (MPPT)based DC-DC converter ensures to match characteristics of load and source impedance for tracking maximum power. In the literature, a number of MPPT algorithms are proposed [4]-[6]. But, still there is a need for improvement in few features of MPPT: steady state response with good stability margins,fast dynamic response for better tracking of optimal operating point.

Particle swarm optimization (PSO) was first proposed by Kennedy & Eberhart in 1995 [7].PSO algorithm maintains a swarm of individuals, where each particle signifies a candidate solution. A particle follows a simple behavior, matches the success of neighboring particles, and improves its performance [8]-[10].

The bacterial foraging optimization algorithm (BFOA) was proposed by Passino in 2002 [11]. This algorithm comprises of three steps: chemotaxis, reproduction and elimination-dispersal. Bacterial chemotaxis is a complex grouping of swimming and tumbling that keep bacteria in places of higher concentration of nutrients. During reproduction, the least healthy bacteria die and the other healthier each bacteria split into two. Thus the population of bacteria remains constant. During the elimination and dispersal event each bacteria is eliminated and dispersed with a probability [12]-[14].

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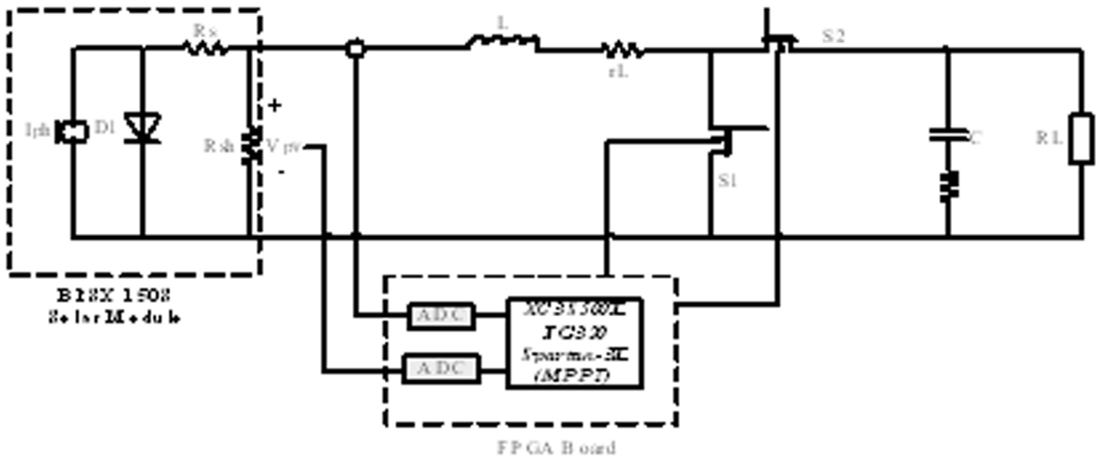


**Figure 1: Block diagram of a Power Conditioning PV system**

This paper proposes an improved MPPT technique by hybridizing PSO and BFOA for better tracking of maximum power point in PV systems. In the proposed technique, the search directions of tumble process for each bacterium are placed by the individual's best location and the global best location of PSO. The block diagram of power conditioning PV system is shown in figure 1.

The paper is structured as follows. The proposed system is discussed in section II. In section III, simulation based design and analysis is described, simulation results are discussed and verified with hardware results. Section IV states conclusions of the paper.

## 2. PROPOSED SYSTEM

### 2.1. Mathematical model of a solar photovoltaic module

The equivalent circuit of PV module is shown in figure 2. A solar cell is a basic element of PV systems, comprising of p-n junction fabricated in a thin wafer of semiconductor, uses the principle of photovoltaic effect, where electrical energy is produced from solar energy. A diode is connected in anti- parallel with the current source. PV modules are formed by a group of PV cells which are connected in either series or parallel, further these PV modules are grouped together to form a PV array.

$$I_{cell} = I_{ph} - I_o \left( e^{\frac{qv_D}{\eta V_T}} - 1 \right) - \frac{V + I_{cell} R_s}{R_{sh}} \tag{1}$$

$I_{ph}$ is the photo current, $I_O$ is the reverse saturation current of the diode, $I_{cell}$ is the output current,the charge of the electron is q, the Boltzmann constant is K, the series resistance is $R_S$ and the shunt resistance

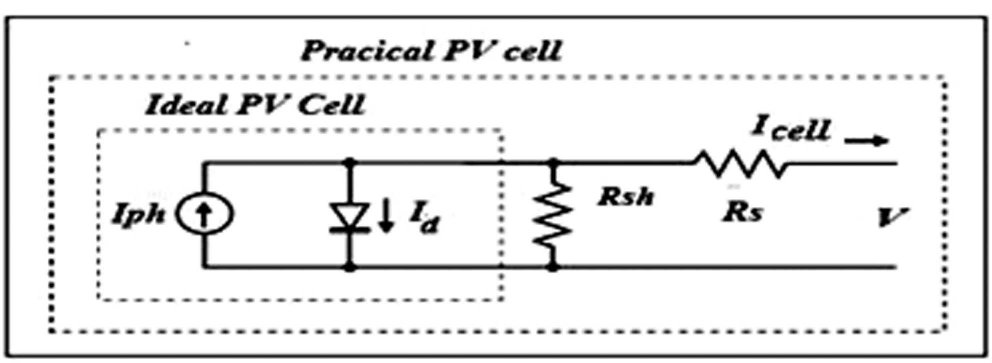


**Figure 2: PV module equivalent circuit**

is $R_{sh}$.The above equations exhibit a nonlinear behavior between $I_{PV}$ –$V_{PV}$, $P_{PV}$ – $V_{PV}$ and $P_{PV}$ - $I_{PV}$. Hence, there is a need for obtaining optimal operating point to extract the maximum power from the solar modules, which is accomplished by MPPT.

## 2.2. Boost converter

A boost converter comprises of a power MOSFET, diode, inductor and capacitor is shown in figure 3; enhances the voltage level, operates in two modes governed by the switch position &conduction of a diode and also matches the load & PV module characteristics. Its designing is illustrated by flowchart depicted in figure 4.

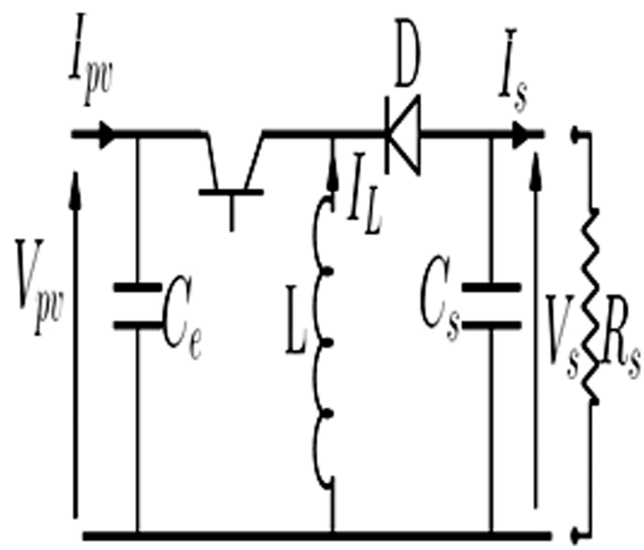


**Figure 3: Equivalent circuit for Boost Converter**

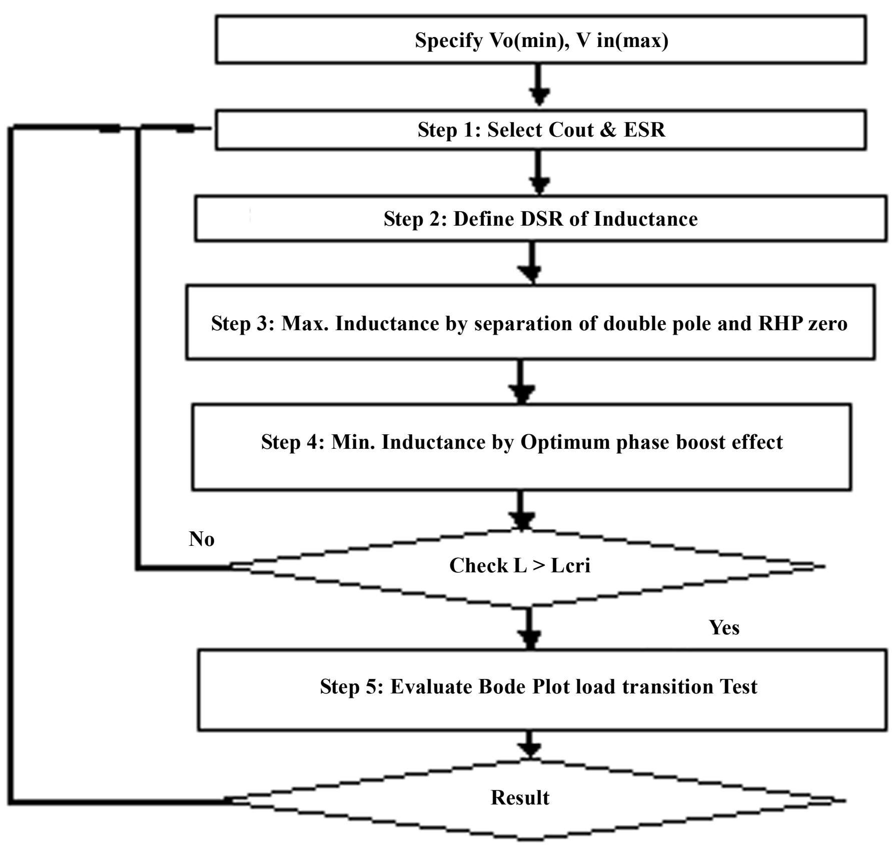


**Figure 4: Flow Chart for Designing boost converter**

### 2.3. Hybrid PSO and BFOA

The proposed work pools two algorithms: PSO and BFOA; uses PSO ability to interchange social information and BFO ability in finding a new result by removal and dispersal. In BFO method, unit length direction of tumble behavior is arbitrarily made. In the hybrid PSO & BFO method, unit length random direction of tumble behavior can be decided by the global best position. During the chemotaxis loop, the update of the tumble direction is determined by:

$$\Phi(j+1) = w * \Phi(j) + C_1 * R_1 (P_{best} - P_{current}) + C_2 * R_2 (P_{gbest} - P_{current}) \quad (2)$$

We can determine the new velocity updated from the previous velocity during the iteration time k with

$$V_{ik} = V_{ik} + C_1 * \mathrm{R}_1 (P_{ilbest} - X_{ik}) + C_2 * \mathrm{R}_2 (P_{iglobal} - X_{ik}) \quad (3)$$

$R_1$ and $R_2$ represent random numbers. The new position is then determined by the sum of the previous position and new velocity.

$$X_{ik+1} = X_{ik} + V_{ik+1} \quad (4)$$

Considering its own experience, each particle decides where to move next, which is the memory of its best past position, and takes the experience of the most successful particle in the swarm [15]-[17]. The flowchart for the design process is shown in Figure 5 and the flowchart for the hybridized PSO & BFO method is shown in Figure 6.

## 3. SIMULATION RESULTS & DISCUSSION

The proposed system is analyzed by Xilinx interfaced MATLAB Simulink based modeling. The output voltage and output current waveforms of PV module are shown in the Figure7 & 8 respectively.

Figure 9 depicts that bode plot of MPPT charge controller with hybridized PSO-BFO based technique and two optimization techniques: PSO and BFO separately.

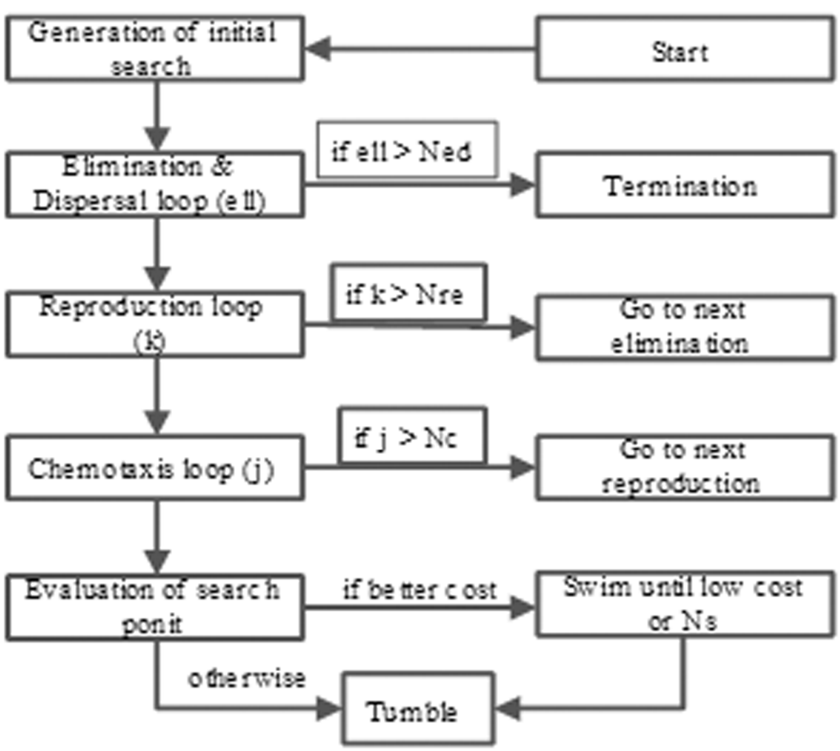


**Figure 5: Flowchart for design process**

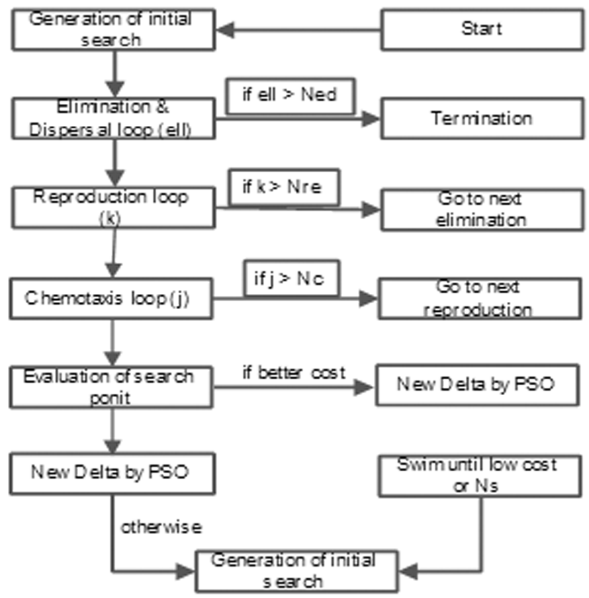


**Figure 6: Flowchart for hybridized PSO& BFO algorithm**

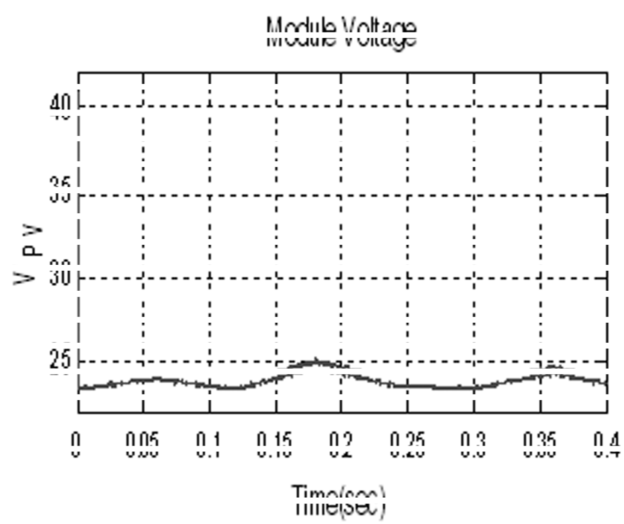


**Figure 7: PV Module output Voltage**

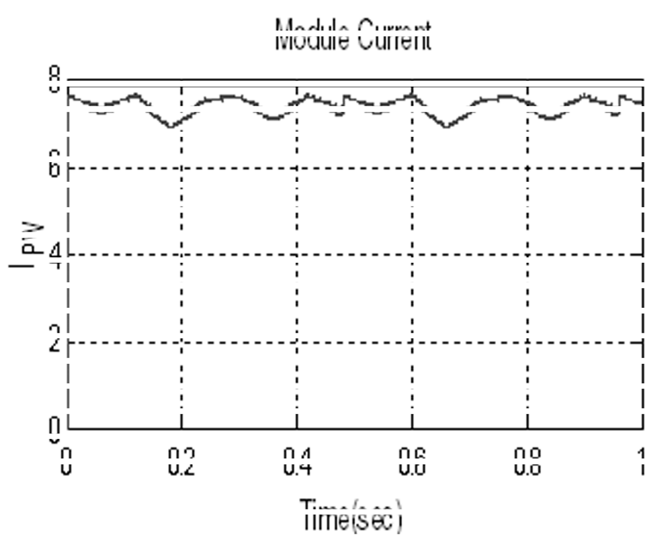


**Figure 8: PV Module output current**

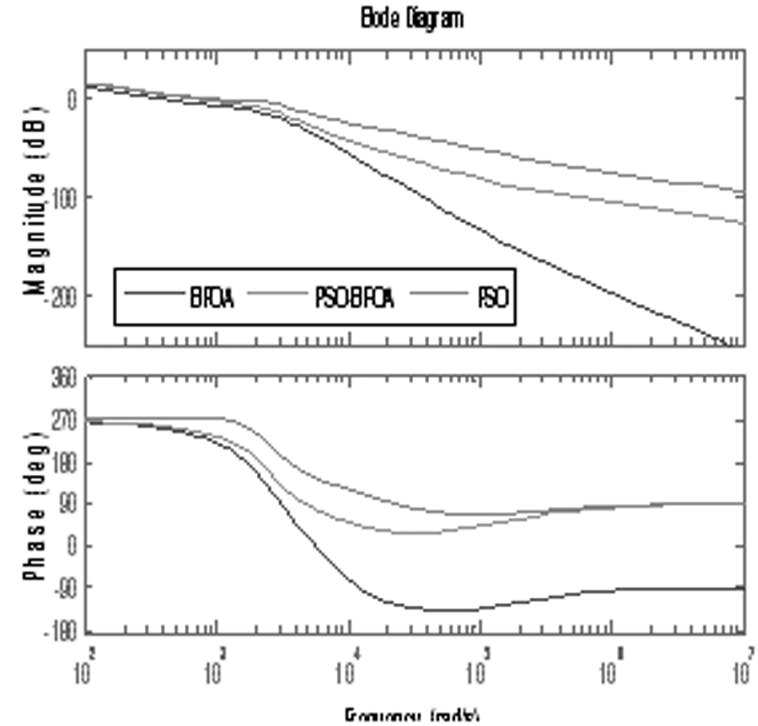


Figure 9: Bode Plots of MPPT Charge Controller

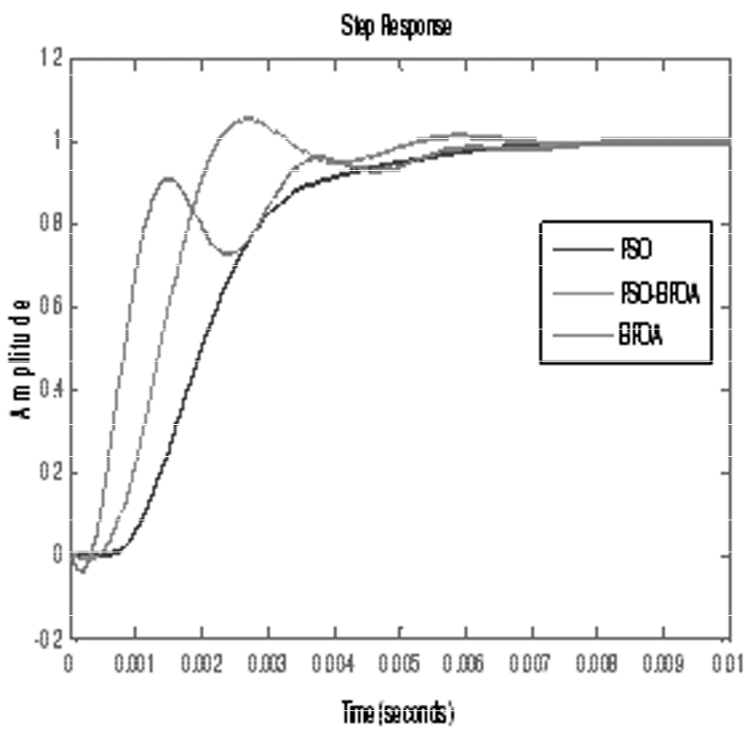


Figure 10: Step Response of MPPT Charge Controller

The closed loop step response of MPPT charge controller with PSO-BFO based and two optimization techniques: PSO and BFO separatelyare depicted in Figure10.

From the Step response, bode plots and Table. 1, it can be observed that PSO &PSO-BFO based technique provides less steady state oscillations. The response using hybridized PSO-BFO method is faster than PSO. Hence, this controller is selected for hardware implementation with FPGA controller. The FPGA based controller chip design is described below.

**Table 1**
**Time domain & Frequency domain specifications of MPPT Controller using different search techniques**

| *Specification* | *PSO-BFOA* | *BFOA* | *PSO* |
|---|---|---|---|
| $T_r$ | 0.00263 | 0.00121 | 0.00171 |
| $T_p$ | – | 0.00268 | – |
| $T_s$ | 0.00623 | 0.00489 | 0.00514 |
| %MP | 0 | 5 | 0 |
| $\omega_{gc}$ | 443 | 757rad/sec | 599 |
| PM | 69.9 | 64.9 | 70.4 |
| $\omega_{pc}$ | 1710 | 2120rad/sec | 2120 |
| GM | 10.4 | 7.9 | 9.7 |

### 3.1. Design of FPGA chip and hardware co-simulation

The above mentioned controller is practically with CPLDs, presented in the following section. System generator, ISE & embedded based integrated flow procedure is used for the execution&confirmation of controller and is depicted in Figure 11.

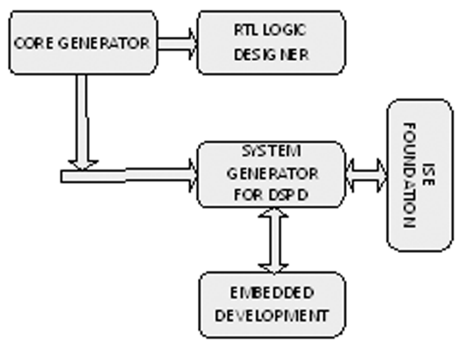


**Figure 11: RTL View of FPGA chip**

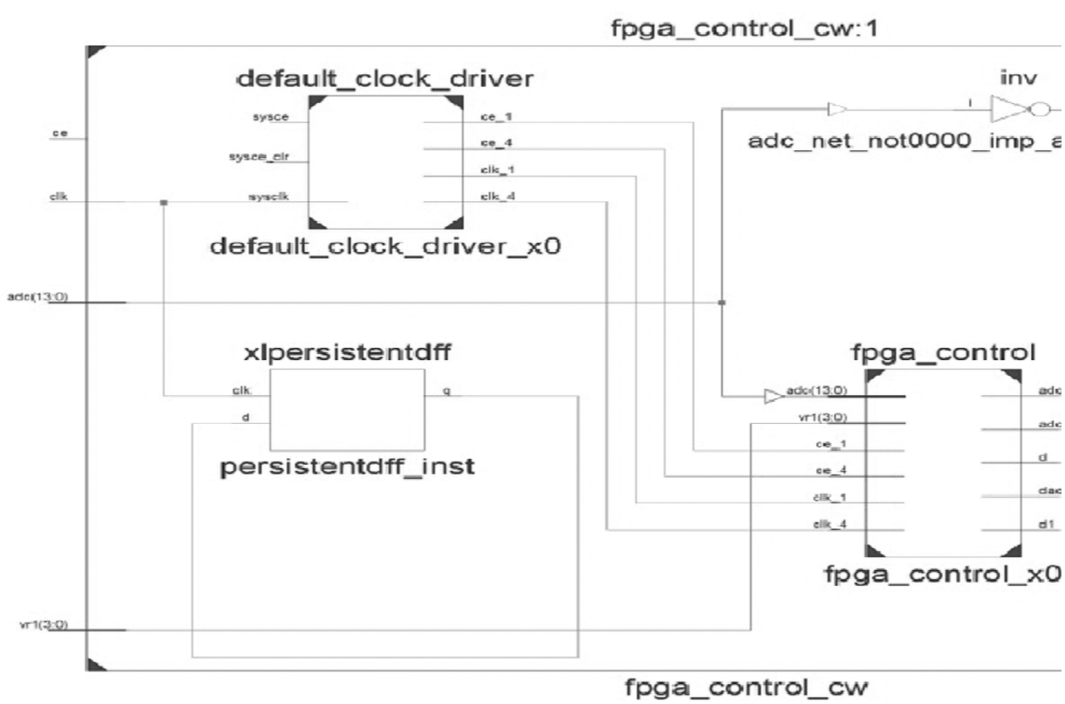


**Figure 12: System generator, ISE & embedded: Integrated flow**

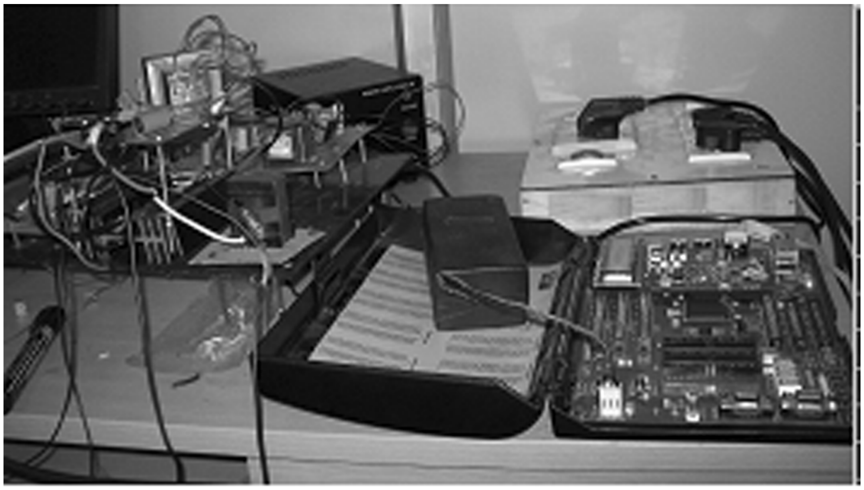

**Figure 13: Prototype of proposed system**

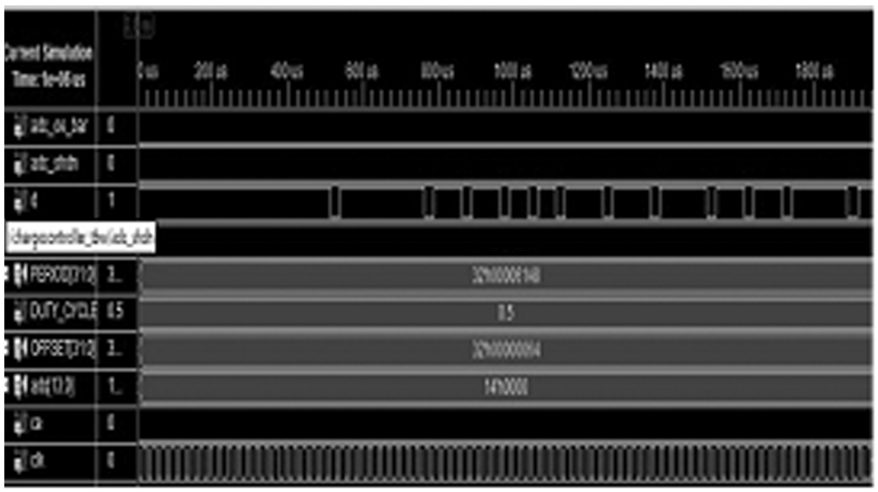

**Figure 14: Behavioral simulated waveform of designed controller**

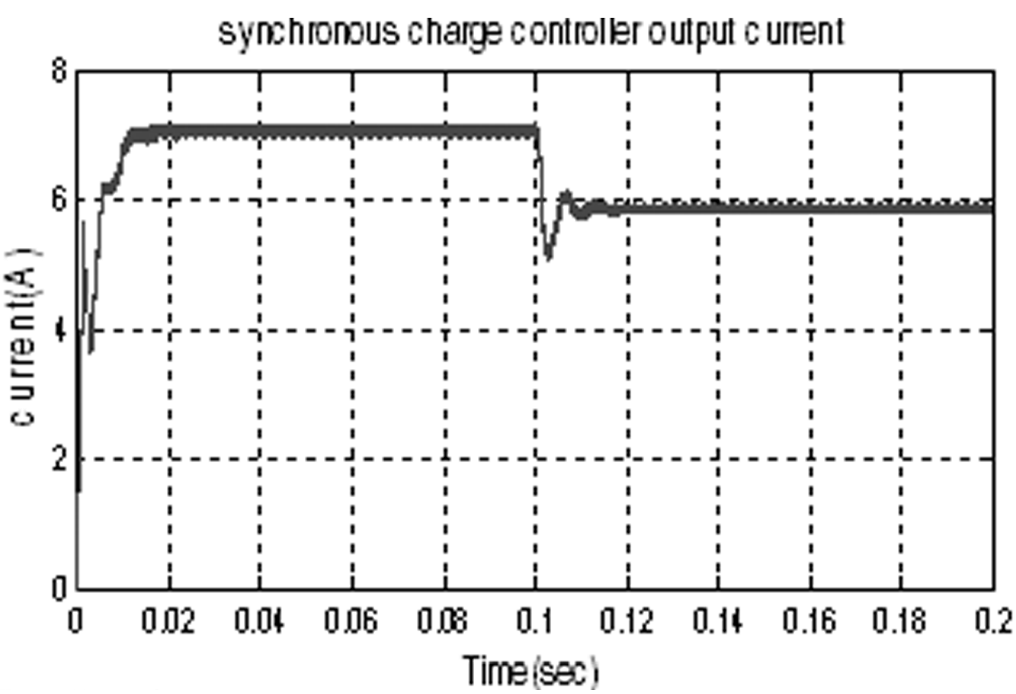


**Figure 15: Hardware co-simulation based MPPT charge controller output current**

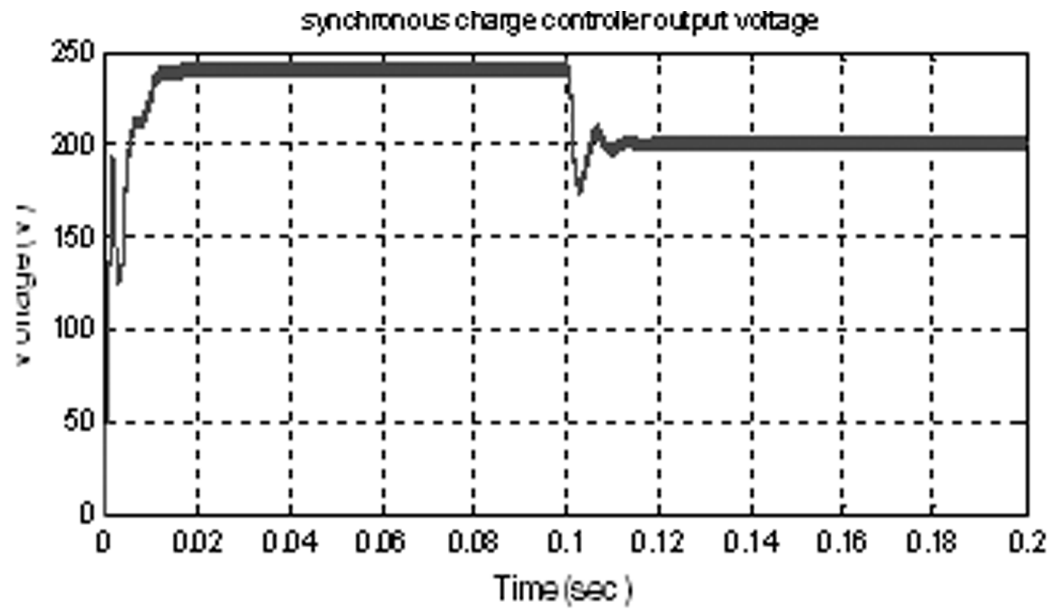


**Figure 16: Hardware co-simulation based MPPT charge controller output voltage**

The controller on an FPGA chip is developed by writing and synthesizing VHDL language based HDL code. Designed controllers RTL view is presented in Figure.12, the prototype of the proposed system is shown in Figure.13 and the generated Gate pulses are shown in Figure.14.

## 4. CONCLUSIONS

The proposed system, "Field Programmable GateArray Chip Design for Hybridized PSO--BFO based Maximum Power Point Tracker," has been successfully designed, simulated on Matlab Simulink and Xilinx system generator environments and confirmed with the prototype development. The results revealed that proposed design offers reduced steady state oscillations; moderate steady state and dynamic performance when compared with PSO and BFOA based MPPT techniques.

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