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FPGA based Photovoltaic Efficient Energy Management with Reversible off-the-GRID Power Supply

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***Abstract* - This Paper proposes an implementation of photovoltaic (PV) energy management of OFF-THE-GRID(OTG) power supply applications by using Simulink and FPGA Board. The goal of the project is controlling SEPIC(boost-buck) converter for the incoming voltages of PV module through PWM technique applied through XILINX ISE and display all significant signals through that requirement(min 11 to max 90 volts). This project includes the control of the chopper (switch) and displaying the values of the current (current sensor) and voltages (voltage sensor) as well as compare with the pre-scale value in various duty cycles. This developed hardware has the merits of VHDL programming through XILINX with high accuracy with constant solar irradiance value. The proposed MPPT (Maximum Power Point Tracking) technique has been described through detailed work.**

Keywords – Photovoltaic, FPGA, SEPIC converter, OTG supply, boost/buck converter

I. INTRODUCTION

'Solar energy' is a vital part in today's energy consumption of our country. This energy is renewable as well as abundant source. Due to shortage and requirements of the increasing population change the impacts of conventional sources like coal, gasoline are making solar energy and wind energy more significance. Particularly, the photovoltaic (PV) system is converting solar energy into electricity is in general efficient and a vital way of electricity generation because it produces the maximum possible output for all weather conditions. PV array has a highly non-linear current/ voltage characteristic varied with irradiance and temperature that substantially affects the array power output in given time domain. The maximum power point tracking control of the PV system is therefore critical for the success of PV system. It is possible to make sure that, even in the Off-Grid conditions (feedback to power grid) the PV part works in its optimal power point, by the usage of MLP-generator, MLP-battery devices by the Simulink-physical signal converter tools.

II. DESIGN PROCEDURE AND ANALYSIS

Perturb and Observe (P&O) method the controller adjusts the voltage by a small amount from the array and measures power. If power increases, further adjustments in that direction are tried until power no longer increases which is called 'perturb and observe method' and is most common, although this method can result in oscillations of power output. It is also known as **Hill climbing** method, because it depends on the rising curve of power against voltage below the maximum power point, and the fall above that point. Perturb and observe is the most commonly used MPPT method due to its ease of implementation. Perturb and observe method may result in top level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

A. *Design of SEPIC Converter*

Single Ended Primary Inductor Converter is essentially a boost converter followed by a buck converter, therefore it is similar to a traditional buck-boost converter. SEPIC is a type of DC-DC converter allowing electrical potential (voltage) at its output to be greater than, less than, or equal to that at its input. The SEPIC output is controlled by the duty cycle(D) of the control transistor. This is done by partially separate in ON/OFF state time transitions in the mechanisms.

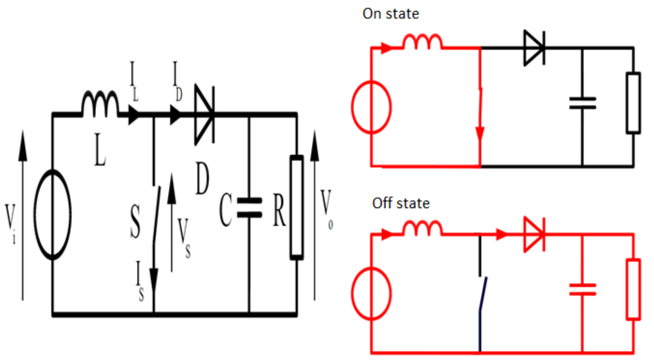


Figure 2.1 Boost converting mechanism

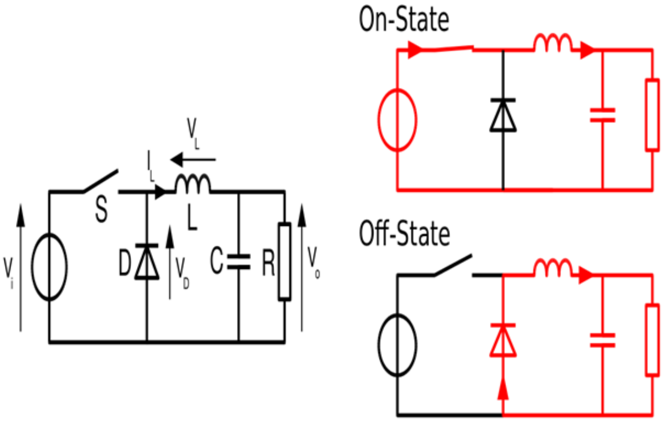


Figure 2.2 Buck converting mechanism

The steady-state voltage and current relations (D - duty cycle) of the converter operating in continuous current mode are given by, with respect to the
duty cycle [D],

Vo / Vin = [1 / (1-D)]
Vo = Vin * [1 / (1-D)]

Finally, D = {Vo –Vin / Vo}

B. Solar irradiance

'Solar irradiance' is the power flow per unit area produced by the sun in the form of electromagnetic radiation. Irradiance measured in space or at the Earth's surface after atmospheric absorption and scattering. **Total solar irradiance (TSI)** is a measure of the solar radiated power per unit area normal to the rays, incident on the Earth's upper atmosphere. Solar constant is a conventional measure of mean TSI at a distance of one **Astronomical Unit (AU)**. Irradiance is a function of distance from the Sun, the solar cycle, and cross-cycle changes with respect to time period.

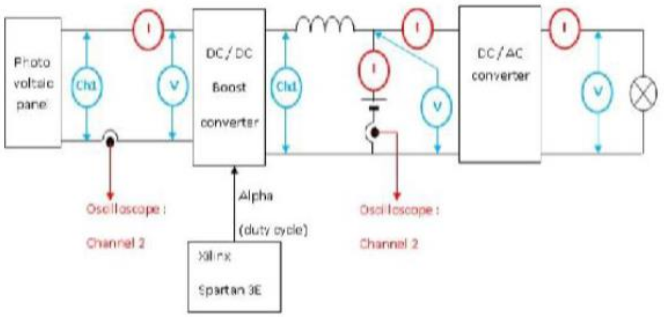


Figure 2.3 The proposed system

PV output voltage(volts)	Boosted output(volts)	Inverter voltage
12.225	60.21	59.12
11.571	80.41	81.40
12.770	85.05	85.93
12.013	90.17	91.02

Table 2.1 - Electrical characteristics

Input voltage (Vin)	12V
Input current	4.1A
Output Voltage	80V (no load)
Output current	26.66 A(no load)
Maximum Power output (P)	52.9W
Switching frequency (f)	16.86kHz

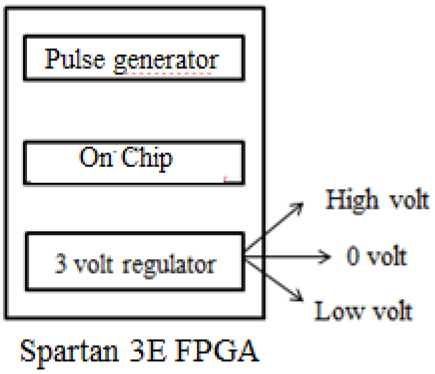
Table 2.2 - Specification of SEPIC converter

III FIELD-PROGRAMMABLE GATE ARRAY

FPGA is an integrated circuit designed to be configured by customer or designer after manufacturing hence it is called Field-programmable. Nowadays, FPGA devices are widely used to build control platforms in various fields of real time applications such as wireless telecommunications, image and signal processing, robotics and renewable energy systems. FPGA configuration is generally specified using a hardware description language (HDL). FPGAs contain programmable logic components called 'logic blocks', and hierarchy of reconfigurable interconnects that allow the blocks to be 'wired together' somewhat like many (changeable) logic gates that can be inter-wired in different configurations. The control algorithm and programmable interconnect with the PV cell is proposed by means of CHIP SELECT(in), DRIVER-IN(out) which is indicated by corresponding LED blinking mechanism at FPGA.

A. FPGA voltage regulators

The PV sources deliver variable power which depends on solar radiation which is 1000 W/m2 during sun hour period. In order to extract maximum power from PV source, solar power regulator has been incorporated which regulates the voltage to respective Maximum power point i.e. the intersection point between load line and V-I curve at different in-solation (radiation) level. This is achieved through intelligent controller unit of solar (PV) converter system.



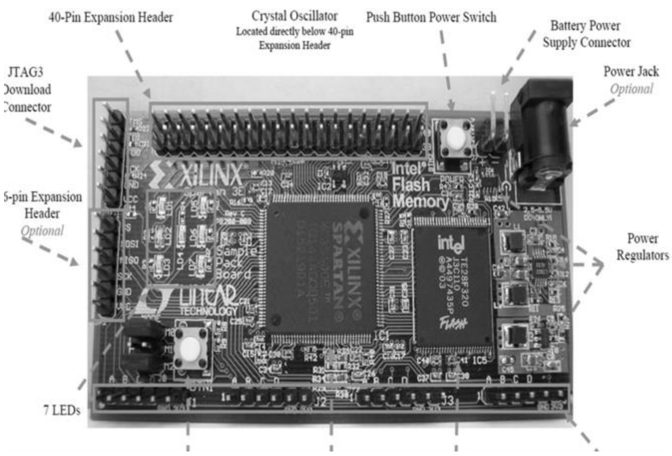


Figure 3.1 Spartan 3E

B. PWM

Pulse Width Modulation is a technique for getting analog results with digital manner. Digital control is used to create a square wave, a signal switched between on and off. In addition, PWM is one of the two principal algorithms used in photovoltaic solar battery chargers, the other being MPPT. Performed PWM technique which provide average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load. In this method PWM modulator combined with FPGA for giving commands to SEPIC converter for the corresponding voltage arrival from PV panel which is sensed by the voltage regulators of FPGA.

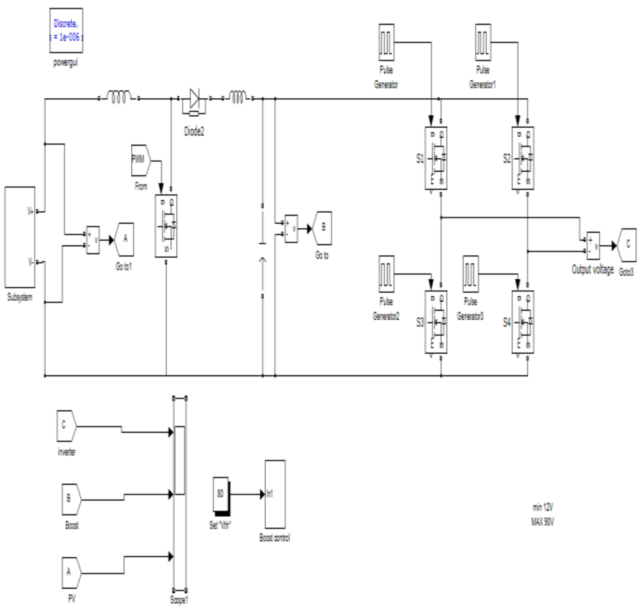
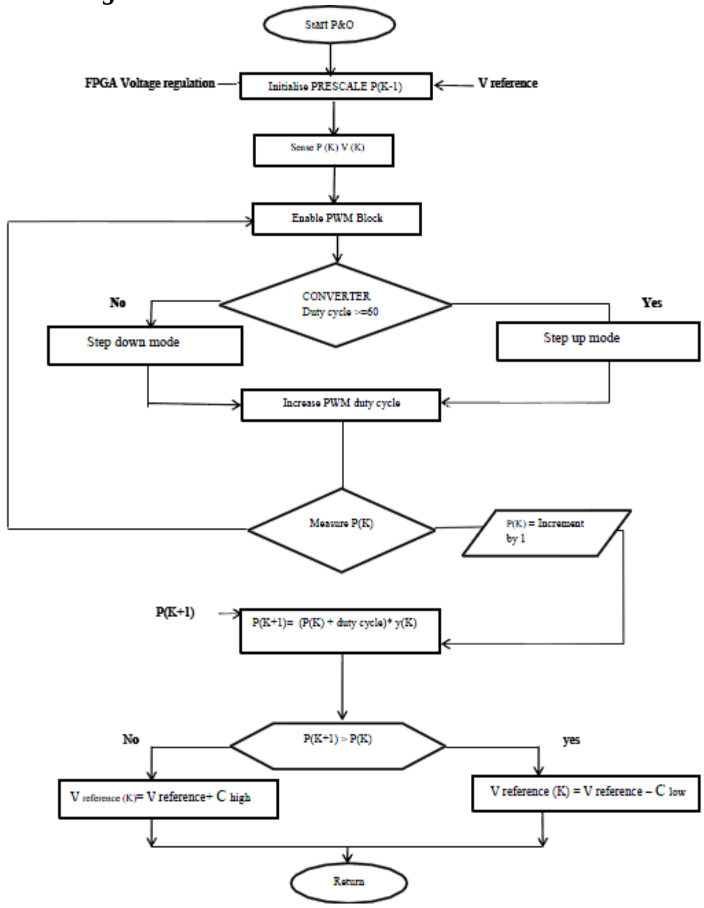


Figure 3.2 The proposed system

The system consists of a solar array, buck converter, XILINX (FPGA) Board, Battery, inverter. Its electrical characteristics can be up to 90 volts. The maximum electrical characteristics obtained during our unrepeatable tests. The scope block displays its input with respect to simulation time. The Scope block can have multiple axis, all axes have a common time range. we move and resize the scope window and modify the Scope's parameter values during the simulation.

SEPIC algorithm



VI EXPERIMENTAL RESULTS

The whole proposed system separated into parts which are constricted and integrated by MATLAB Simulink environment. The proposed setup has been tested at different time durations in a day (T1, T2, T3) to ensure the testing is done for different environmental operation conditions. Fig.1-3 show the performance results obtained from the proposed setup for different time duration with different load. Table is done for maximum power at 52.9 Watt, output voltage at no load=80 volts and duty cycle 0.74 where you can see that current is not exactly constant.

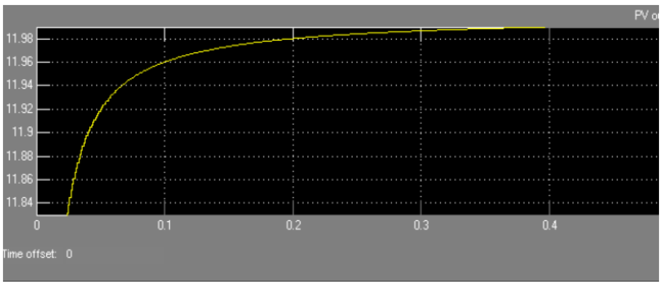


Figure 4.1 PV panel voltage = 12 volts during time T1

At time T1, PV panel incoming voltage by the help of 'solar irradiance a's well as solar constant(air mass constant 1.5 to 2) is around 1000 in a range(36 cells solar module).While varying solar cells range, its gain should be high (without any load). From figure-1, 11.99 volts is reached through PV panel time offset scale at a day.

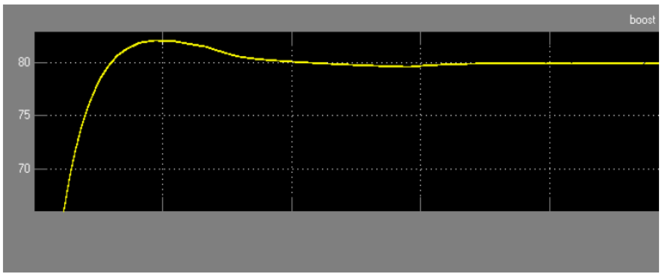


Figure 4.2 Boosting voltage = 80 volts during time T2

From this figure, SEPIC converter acts into step-up (boosting) mode for increasing 12V PV panel incoming voltage value. While connecting load with the battery output, it produce slight variations in the duty cycle period. (I battery> 0 is known as battery in generator mode). Main advantage of SEPIC converter is we can fix the step up/down voltage(In figure setting 80 Volt) prior as a pre-scale value, to compare with the SIMULINK output theoretical value (figure 2: boosting dc voltage=83V)

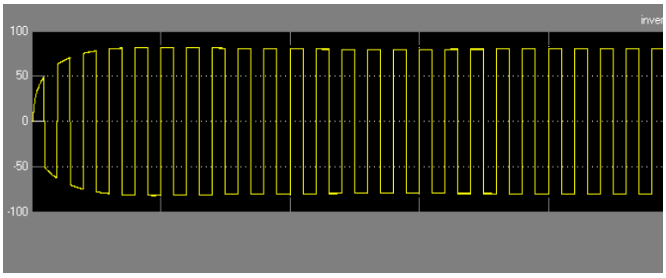


Figure 4.3 Inverter output voltage (dc to ac)= 80 volts during time T3

Normally ‘inverter’ used to change DC voltage & current into AC voltage & current within particular half cycle. Because DC voltage is unidirectional and so we can’t use this in household appliances .but AC voltage is bi-directional (equal polarity to both directions).When converting 80 DC voltage into AC voltage within time period (T3) to shown as AC sinusoidal pulses. Following diagram shows that in a single SCOPE could able to find 3 outputs in common time period (T). The whole solar energy is going through the battery which is in charging mode.

V CONCLUSION

This proposal represents that solar electricity in an efficient way to control the SEPIC converter through FPGA with MPPT tracking to feed a load which consumes energy from that battery directly connected to panel, and display all the significant signals. Therefore, to make hardware for compared output calculations into expecting output values in efficient manner. This has all been done, and the whole project works including the control of the chopper and displaying the values of the currents and voltages. It would have been better to control the proposed system in open loop system that we used. It checks for output power of the array and compares its varied to the direction of perturbation of the operating voltage of the array itself. Using these different methods, PV array response has been analyzed by simulating temperature and insolation parameters.

In future this generating excess electricity (greater than requirement) is feedback into national grid in a reversible process through MLP generator with fuzzy controlling algorithms. Hybrid PV converter system back up with standby source proposed in this study for rural home based load applications is considered as appropriate design for developing countries like India where power cut happens very frequently and it provide the sufficient back up supply.

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