

Digital controlled high power synchronous boost converter based MPPT charge controller for SPV system

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Abstract- Degradation of fossil fuels emphasis to hunt the alternative way of power generation, power electronics made it possible to extract the power from renewable energy sources effectively and efficiently according to need of electrical loads. In this research paper, the main focus is, designing of central level (high power) synchronous based DC-DC converter for the maximum extraction of power from solar PV system at higher DC-DC conversion efficiency, better performance and stable operation. In this paper proposed system, 1.2kWp.rated synchronous MPPT charge controller is designed and simulated, with central level configuring in SPV systems at very high switching frequency, used not only to extract the maximum power from solar array but also for matching the input solar power characteristics with load characteristics. This closed loop control algorithm, for MPPT based synchronous converter, designed and implemented in the digital domain, for direct deployment of FPGA controller. Also presented, small signal analysis of converter, the double lead integral controller design in association with MPPT algorithm in s-domain, converted to digital domain based on bi-linear transformation, deployed into FPGA. The Xilinx interfaced MATLAB simulation results demonstrate that, proposed MPPT based synchronous converter offers maximum power from solar arrays extraction at high efficiency, better dynamic performance in stable region.

Keywords — Synchronous Boost Converter, Digital control, FPGA, MPPT, DC-DC Converter, Constant Voltage Mode MPPT.

I. INTRODUCTION

With the changing phase, being technologically advanced and economically reputed is a must in the world. It is a must in order to face the competition and also exists among the top powerful people. On the other hand, energy crisis is one of the major problems which every country is facing in this era. The developing countries are least capable of taking a step for the crisis as they are completely dependent on developed countries for their technological growth. It is fact that the non-renewable resources i.e. fossil fuels have limited reserves, they are used very roughly by setting the mind for the future and therefore they are depleting at a very fast rate and existing technology is incapable of controlling its depletion as they are fulfilling our requirements easily. There are various problems also that occur from the usage of fossil fuels like the cost of fuel in its extraction and usage, and the harm that they cause to the environment. These are the problems which are forcing the scientific research scholars to shift their mind set up from nonrenewable energy sources to renewable energy sources. With the rising energy demands, it is required to utilize the renewable energy resources. It is the right time now, before time elapses, betters to shifts the world energy scenario from non-conventional to conventional energy sources. Among the various renewable energy sources, the most useful, efficient, pollution free and very commonly used is solar energy. It is a leading source of energy which is abundant in nature. But it has not been properly utilized in a right direction due to technological problems. All professionals in this field have to work and go beyond the technological advancement so that everyone can utilize the solar energy and full fill the needs of the world.

A lot of literature has been reported regarding synchronous based dc-dc converters for different types of applications by researchers. In [1], a new dynamic, non-inverting, synchronous buck-boost converter is designed for portable applications and validated through experimental results. In [2], authors developed a mixed synchronous/asynchronous digital control in a FPGA (Field Programmable Gate Array) using VHDL language

to DC-DC boost converter, observed that the controller offers high dynamic performance, frequency modulation during transients, no quantization effects, and low-complexity. In [3], authors presented a work on the stability analysis of a non-inverting synchronous buck-boost DC/DC power converter for a solar power management system under the rapid changes of the atmospheric condition or sunlight incident angle, results of this work show that the stability margins depend on the inductor and capacitor selected for the converter and depend on the load conditions also. In [4], a new control method for H-bridge buck-boost converter regulated by single voltage feedback and dual feed forward controls with synchronous-buck and synchronous-boost operating modes, to suit the battery powered applications, resulted that the admirable transient performances for the step load variation without pampering the efficiency for wide range of the supply voltage. In [5], a novel cost effective and efficient microcontroller based MPPT system for solar photovoltaic system for all fast changing environmental conditions proposed, offers that high-efficiency, lower-cost, very fast tracking speed and can be easily modified. In [6], a zero-voltage switching (ZVS) synchronous boost converter is proposed, and states that to achieve optimum efficiency at a range of load conditions, the magnitude of the resonant current must be controlled. In [7], robust digital voltage-mode controller design for a synchronous soft-switching boost converter is presented, the small-signal z-domain transfer functions of several operating modes are formulated using system identification toolbox of the MATAB, and then used to design controller in digital domain. To achieve the higher efficiency and reliability with lesser number of components for higher power rating applications Multiphase interleaved synchronous boost converter became a best choice. In [8], three different inductor winding designs are presented to optimize the overall efficiency in a multiphase interleaved bidirectional boost converter. In [9], new control method for Boost converter in discontinuous conduction mode (DCM) to realize synchronous rectification (SR) of the rectifier and zero voltage switching (ZVS) of the power switch and proves that optimizing its operating characteristic can improve the ability of whole device. In [10], a comparative analysis between DMPPT Synchronous Rectification boost converter and Diode Rectification boost converter is carried out and determined the efficiency performance, thermal behavior and reliability by numerical and experimental data, based on the analysis demonstrated that the Synchronous Rectification boost converter is better for the PV system efficiency improvement and thermal requirements. In [11], presented a FPGA controlled power conditioning system controlled with FPGA for solar PV fed systems. In [12], implementation of open circuit voltage MPPT controller for solar PV System based on FPGA, mathematical modeling of solar module and design of DC-DC converter and small signal analysis of charge controller are presented.

Based on rigorous study of above literature following conclusions can be made:

- FPGA controlled dc-dc converters offers high dynamic performance, frequency modulation during transients, no quantization effects, and low-complexity [2], [11-12].
- Small signal transfer function of converters is necessary for the proper design of controller for all types of disturbances and stability analysis [3],[7].
- For all fast changing environmental conditions in solar PV system digital controllers can offer that high-efficiency, lower-cost, very fast tracking speed and can be easily modified [5].
- Synchronous Rectification boost converter is better for the PV system efficiency improvement and thermal requirements [8], [9], [10]

None of the aforementioned literature considered FPGA controlled synchronous boost converter based MPPT charge controller to extract the maximum power from solar PV modules/arrays with better thermal requirements. Hence, this research study proposes a system to achieve above mentioned properties. Further, contributions will be extended towards development of transfer function using system identification toolbox of the MATAB, design controller and converts to digital domain for direct implementation of controller in Xilinx system generator interfaced MATLAB Simulink environment for the deployment of code into FPGA.

II. PROPOSED PV SYSTEM

The proposed PV system comprises power conditioning unit, not only to extract the maximum power from solar array but also for matching the input solar power characteristics with load characteristics. The main elements of PV systems are solar PV array, power conditioning system, energy storing element and the load. Proposed power conditioning PV system for DC loads is shown in Fig.1.

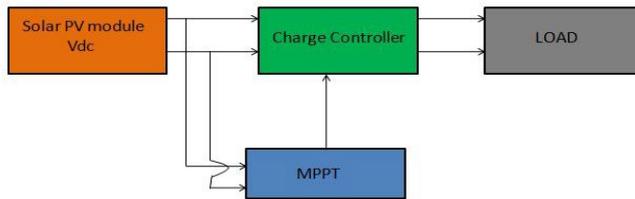


Fig.1. Block diagram of power conditioning PV system.

A. PV Module:

A solar cell is basically a semiconductor element, which can absorb light energy and converts into electric energy. Different solar cell combines to form PV module in order to increase the power level. The output in terms of voltage/ current of a module depends upon the type of combination that is a series or parallel combination. Combination of several modules in parallel or series, the array can be formed at high power level [11-13].

The output of solar panel is variable D.C, exhibiting non-linear properties, depends upon its ambience irradiance and temperature. An increase in the ordinance will increase the open-circuit voltage and short-circuit current of the solar cell. On the other hand increase of temperature will increases the short-circuit current but decreases the open-circuit voltage.

Synchronous Boost Converter:

Synchronous boost converter is the modified version of the boost converter, in which the diode used is replaced by a transistor (MOSFET'S) called second controlled switch. Because of second switch, the cost and efficiency both are increasing, very high efficiency made compromises with the cost. In standard boost converter the diode turns on its own after the switch is off, as in addition to this there is a rising voltage across the diode which results in the power loss. To overcome these losses, a transistor (switch 2) is used in the place of diode which is synchronized with the switch 1. As PWM deals with the constant frequency and the T_{on} time is varied, therefore the power loss is totally dependent on the duty cycle D and thus switching time. In synchronous boost converter the PWM is applied directly to the switch 1 and with a NOT gate to the switch 2, called both switches are in synchronized fashion, whenever the switch1 is turned OFF, the switch 2 automatically turns ON, and vice-versa. Hence, fully controlled switches are controlled as per our requirements to get desired output.

The prime benefit of the synchronous boost converter, is that, it can respond to the fluctuating loads quickly without any delay, without the switching losses that were previously getting when diodes were used and too much extent the switching ripples can be minimized. Another advantage of the synchronous boost converter is that it can be bi-directional, whenever the power in switched from the load end, it can work as synchronous buck converter and hence this application can be utilized in DC motors. Due to the use of 2 transistors the heating losses can be also minimized as compared to the diodes and we can also enjoy the different advantages of the transistors (MOSFET's) as a comparison to the diodes.

As use of 2 semiconductor transistors offers a wide range of controlling the switching frequency and many other advantages mentioned above, it has some disadvantages like the cost increases and if both switches are not synchronized properly it can lead to the failure of the circuit and to reduce the switching time, some extra circuitry needs to be added which increases the complexity. But beyond all these disadvantages we are improving the efficiency which is the main motive.

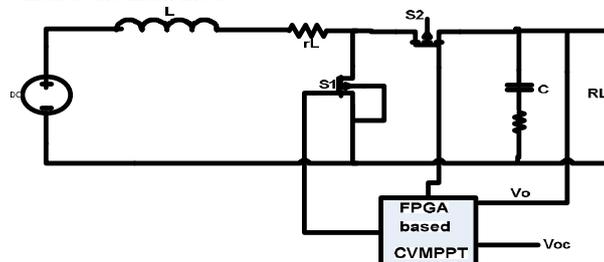


Fig.3.circuit diagram of synchronous based MPPT charge controller

MPPT Techniques: Maximum Power Point Tracking in solar PV, trying to extract the maximum possible power from the panels at unique operating point. The I-V and P-V characteristics of a PV cell depend upon the solar

radiation intensity and temperature [5]. By varying and controlling the different parameters of the panel like current, voltage or both, zenith can be reached. The fractional open circuit voltage method is the easiest and cheapest in implementation point of view and can extract maximum power point with much delay. The V_{MPP} and V_{oc} has a linear relationship which can be given by [8]

$$V_{MPP} = k * V_{oc} \tag{1}$$

Where V_{oc} is open circuit voltage, V_{MPP} is the maximum power point voltage. The factor k is usually between 0.71 and 0.78 [7-8], hence the V_{MPP} can be calculated and set as a reference. The output voltage from the DC-DC synchronous boost converter is measured and compared with V_{MPP} and the error is used to calculate the required PWM for switching the MOSFET's and hence the maximum power can be achieved by equivalent calculations.

Field Programmable Gate Array

A Field Programmable Gate Array (FPGA) is pre-fabricated device that can be electrically programmed to become any kind of digital circuit. It is an integrated circuit which is an array of logic cells. It can be made or designed as requirement of users.

In this paper the proposed system is controlled with the help of FPGA i.e., the CVMPPT method is programmed in VHDL by using Xilinx space system generator to control the DC-DC boost converter.

SIMULATION RESULTS

To analyze the proposed system, Xilinx interfaced MATLAB Simulink based modeling has been performed after done proper mathematical design.

In MATLAB solar PV module is modeled with the following specifications as Shown in Table.1.

Table.1 Design specifications of Solar PV Module

Data Sheet Values		Estimated Parameters	
Isc (Short circuit current)	7.36A	Iph (Photon current)	7.36
Voc (Open circuit voltage)	30.4V	Io(diode current)	0.104μA
V_{mpp} (Voltage at maximum power)	24.2V	A (Diode factor)	1.310
I_{mpp} (Current at maximum power)	6.83A	Rs (series resistance)	0.251Ω
Ns (No.of Series connected solar cells)	50	Rsh (Shunt resistance)	1168Ω
Temperature Coefficients			
Ki(Temperature Coefficient for current)	0.057%	Kv (Temperature Coefficient for voltage)	- 0.346%

By using the above data, PV module is modeled in MATLAB and shown their characteristics; output voltage and current waveforms are shown in following figure.

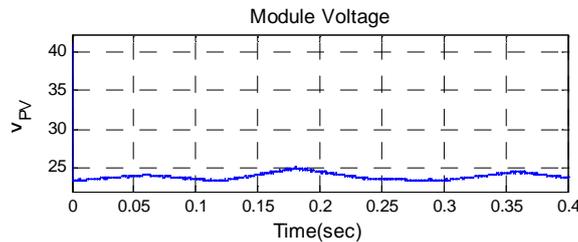


Figure9: Solar Module output Voltage

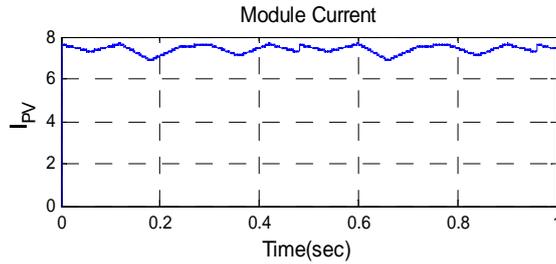


Figure10: Solar Module output current

Design specifications of MPPT charge controller:

Input Voltage= 24V, Output Voltage= 60V Output Power = 165W, Switching frequency = 20 KHz
 Inductor =700μH, Capacitor C= 470μF and their parasitic elements ESR of inductor = 0.019Ω, ESR of capacitor = 0.111Ω, internal on-state resistance of MOSFET= 0.18Ω and on-state voltage drop of diode = 0.8V
 Step 2. extraction of transfer function from MATLAB Simulink for small signal analysis of charge controller and to design suitable controller in digital domain

$$\text{Plant transfer function} = \frac{-5.943e^5s + 6.021e^8}{s^2 + 1264s + 1.247e^6}$$

Parameterization:

Number of poles: 2 Number of zeros: 1

Number of free coefficients: 4

Use "tfdata", "getpvec", "getcov" for parameters and their uncertainties.

Estimated using TFEST on frequency response data "sysData".

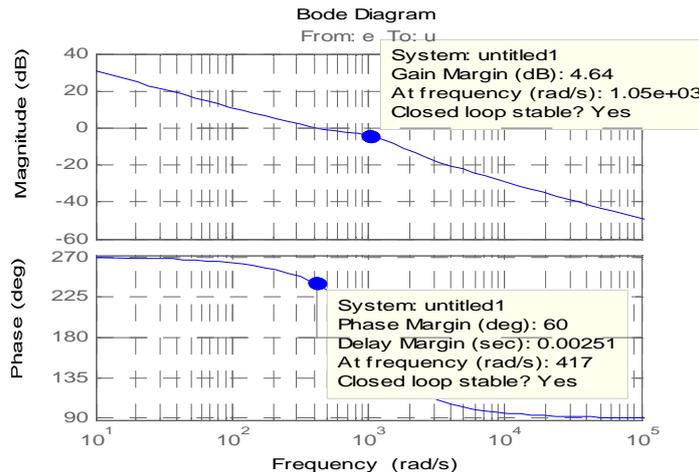
Fit to estimation data: 95.04% (simulation focus)

$$\text{Plant and modulator transfer function} = \frac{-2476s + 2.509e^6}{s^2 + 1264s + 1.247e^6} \cdot \frac{-0.14s + 174.2}{s}$$

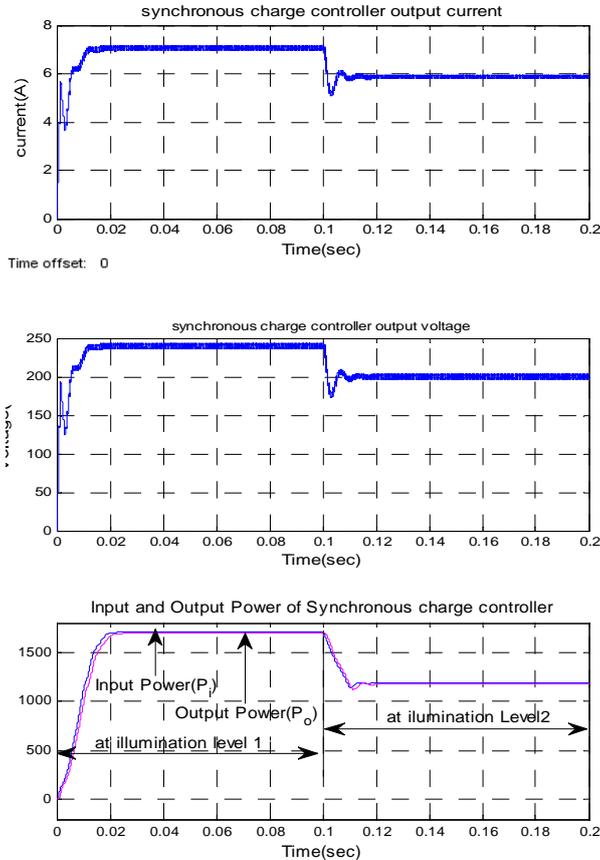
Continuous-time controller transfer function =:

P= 0.13996, I= 174.2151, D=0, N=100

Performance and robustness Tr=0.00157, Ts=0.0152, %Mp=17.2, Peak = 1.17. GM = 4.64, PM= 60, Wpc=1052rad/sec, Wgc=417, Closed loop stable



Step 3. Implementation of designed controller on Xilinx system generator platform and control the power circuit in Simulink model for the integration of total system.



III. CONCLUSION

FPGA controlled dc-dc converters offered high dynamic performance, frequency modulation during transients, no quantization effects, and low-complexity. Small signal transfer function of converters is necessary for the proper design of controller for all types of disturbances and stability analysis. For all fast changing environmental conditions in solar PV system digital controllers can offer that high-efficiency, lower-cost, very fast tracking speed and can be easily modified. Synchronous Rectification boost converter is better for the PV system efficiency improvement and thermal requirements.

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