Simulation, Design and Implementation of Various MPPT Systems for Micro Cube-satellite Application

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***Abstract* - This paper discusses the Maximum Power Point Tracking (MPPT) system developed for Electrical Power System (EPS) of COEP Satellite Initiative's second satellite mission. Primary scientific objective of the mission is orbit raising using solar sails with radiation monitoring data collection. This mission has higher energy requirements as compared to first mission, Swayam, this necessitated the implementation of MPPT along with deployable solar panels. The MPPT system which connects to Li-ion battery also functions as battery monitoring and protection system (BMPS). BMPS designs are also examined. The MPPT controller controls switching of a DC-DC converter based on SEPIC topology. This topology provides flexibility in solar panel and battery pack configurations as the input can be higher or lower than output voltage making the design generic along with utilisation of all operating points. An integrated system including solar array, MPPT controller, SEPIC converter and battery pack is simulated in SIMULINK of MATLAB which facilitated tuning and optimization of critical parameters. Various algorithms considered for MPPT are evaluated in brief of which-'Perturb and Observe (P&O)' is discussed in detail. Design and limitations of many commercially available ICs are discussed. Various design techniques for implementing MPPT on controller have also been discussed.**

Keywords - MPPT (Maximum power point tracking), SEPIC (Single ended primary inductance converter), PWM (Pulse width modulation), EPS (Electrical power system), P&O (Perturb and observe)

I. INTRODUCTION

The scientific objective of the mission - demonstration of solar sails, demands rotation of the satellite every instance for maximum orbit raise. Area available for solar energy harvesting in a 3U satellite is limited, which is further minimized by sails preventing sunlight illumination over satellite's lateral surfaces. MPPT is very essential in such missions ensuring complete utilization of available irradiance.

II. SOLAR PANEL AND BATTERY CONFIGURATION

The designed MPPT system will be used to charge the Li-ion battery pack. The proposed EPS in the mission[1] which will be launched in low earth orbit (LEO) has solar panel configuration as below.

Table [1]. Solar panel configuration details

Parameter	**Value**
Solar cell Voc	2.5 V
Solar cell Isc	450 mA
Number of solar cells	36
Solar Panel	Two solar cells in series
Number of solar panels	18
Total maximum power generated	32.6 W

All the panels in deployed configuration are structurally co-planar. The amount of solar radiation falling on the solar arrays will be same. This enables the use of a centralized MPPT system.

III. DC-DC CONVERTER

SEPIC was the chosen topology for the DC-DC converter to implement MPPT using controller.

A. Modelling and Simulations of SEPIC in SIMULINK[2]

Simulink simulations helped to optimize the different component's values, frequency of PWM, step size for duty cycle and various other related parameters. A variable amplitude and frequency PWM generator is made to drive a low-side MOSFET switch. The results for various duty cycles are summarized in the simulation results graph [1] and graph [2]

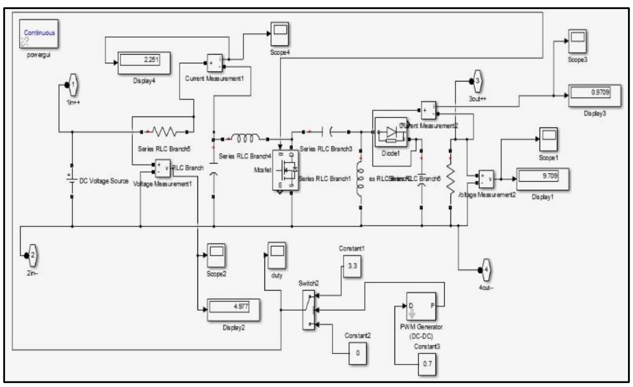
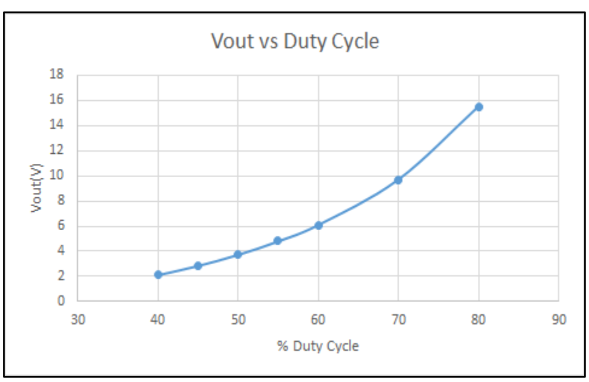
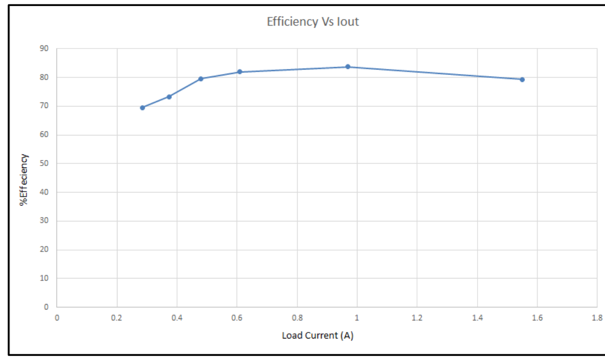


Figure [1]. SEPIC modelling in Simulink



Graph [1]



Graph [2]

B. Practical implementation

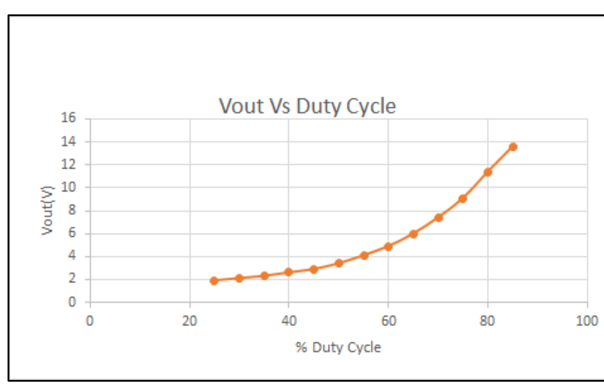
The passive component used in the practical implementation of SEPIC are listed in table [2]

Table [2]. Values of passive component used

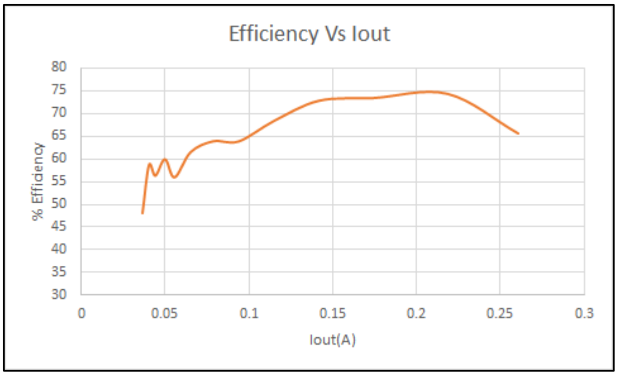
Component	Specification
Inductor	33.8 µH
Capacitor	448.087 µF

Diode: SS12P3L Schottky diode is selected as the forward drop is very less (0.38V). It has a maximum current rating (12A) and reverse voltage rating of 30V.

MOSFET: CSD18534 was selected. It is an N-channel MOSFET with current rating 45A and maximum drain to source voltage of ± 60V which suits the design. It has a threshold voltage of 1.9V allowing it to be switched by controller. It has a maximum turn on and turn off delay of 10ns.



Graph [3]



Graph [4]

Above graphs illustrates the results obtained in practical implementation of SEPIC.

IV. MPPT ALGORITHMS

Table [4]. Comparison of different algorithms [3] of MPPT

Parameter	P&O	Incremental conductance	Voc Method	Isc Method
Speed (for varying irradiance)	High	Medium	Low	Low
Complexity	Low	High	Low	Low
Computation	Low	High	Low	Low
Accuracy	Medium	High	Low	Medium
System Efficiency	High	High	Medium	Medium

P&O is the most suitable algorithm considering its overall suitability in the EPS of the satellite.

V. MODELLING AND SIMULATION OF MPPT TRACKER SYSTEM IN SIMULINK

A. Simulation objectives

1. To test the performance of MPPT algorithm integrated with SEPIC.
2. To estimate the efficiency of the system and get insights into system trends while Modelling and Simulation of MPPT tracker system in Simulink
3. To analyze how the SEPIC converter behaves and the charging profile for Li-ion battery when its duty cycle is controlled by an MPPT algorithm.

B. Overview of Simulation

The model consists of Solar panel model cascaded with SEPIC, MPPT controller, load and batteries. The MPPT controller is used to implement Perturb and Observe (P&O) [4]. The solar panel is modelled based on single diode photovoltaic model using the blocks in MATLAB's Simulink.

The solar panel is customizable as temperature, irradiance profile, series and parallel resistances can be changed as per the specifications of different panels. The frequency and amplitude of the PWM that is generated by the controller is changed and observations are made. The resolution of the duty cycle is also adjusted along with the step-size in duty cycle used by P&O algorithm. Different battery configuration are also be tested. This helps in fine tuning the Frequency and step size of PWM.

VI. MPPT USING CONTROLLER

A. Generating PWM with the controller

MPPT algorithm P&O has been implemented in MSP430F5529 to test the feasibility of MPPT using a microcontroller. The microcontroller used has maximum timer module[5] frequency of 16.25MHz. When PWM frequency was set to 500 KHz, 1% minimum possible change in the duty cycle was obtained, but our required resolution is higher (around 0.03%) which will require the timer module frequency to be around 1.6 GHz. This is not feasible as the required frequency is too high and no commercially available microcontroller has such a high frequency. Also, the consumption of the microcontroller increases with increase in its operating frequency. The requirement of high resolution PWM is evident from the calculations below:

Considering 10-bit ADC at input of converter, it can sense (5/210) V ~5mV, so the minimum variation in the operating point Vmpp that can be made is 5mV, and considering worst case assumption of current to be 7A, the loss at this operating point will be 35mW, this is a significant amount of power loss as two controllers on-board can operate on this power. So, to attain perturbation of 5mV the change in duty cycle required is 0.03%. For this resolution to be feasible, a microcontroller needs 16 bit registers and frequency at which the counts are made for generating PWM should be 1.6 GHz. (i.e. the frequency of the timer module.) (1.6 GHz = 500000/0.03%).

The selected microcontroller ATSAM4SD32C has maximum clock frequency of 240MHz and no such controller is available which has such a high frequency.

B. Generating PWM using a programmable external PWM circuit

This approach was to use an external circuit[5] which will take input as an analogue voltage and give output as PWM. The idea is to use a microcontroller to calculate the analogue voltage and using the in-built DAC it would convert the digital voltage to analogue and feed it to the PWM IC.

The PWM IC should be sensitive enough to sense 5mV and give a change of 0.03% in the duty cycle. The selected IC is LTC6992-1. Its PWM is controlled by 0V to 1V analogue input. It has a duty cycle range of 0% - 100%. The maximum frequency is 1Mhz. These specifications satisfy design frequency demand but the control voltage range (0V-1V) of this device is a major limitation while using it. The same function can be implemented using analogue PWM circuit designed using operational amplifiers. The circuit includes combination of triangular wave generator and comparator. In this circuit, the triangular wave is compared with the control voltage generated by DAC after implementing perturb and observe algorithm. The DAC of the device ATSAM4SD32C has output voltage range from 0.4 V to 2.4V. The DAC of this device is 12-bit which results into 0.5 mV/bit approximately. Texas Instruments' OPA2365 is selected to be used as a comparator in the design. This device has an offset voltage of 0.1mV in normal operating conditions thus, satisfying the comparator's input difference voltage resolution requirement of 0.5 mV.

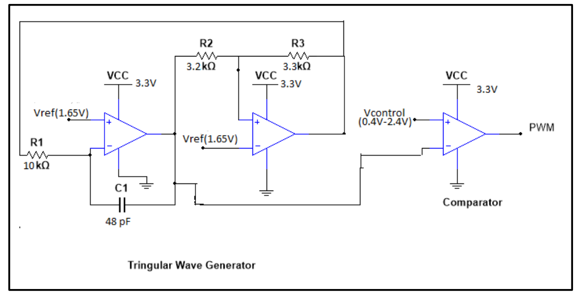


Figure [2]. Analog PWM circuit

The frequency of triangular wave is given by

$$f = \frac{R3}{4 * R2 * R1 * C1}$$

Table [5]. Parameters of Analogue PWM Circuit

Parameter	Value
Positive supply voltage	3.3 V
Negative supply voltage	0 V
Range of triangular wave voltage	0.05V to 3.25V
Frequency of triangular wave	530 KHz
Control voltage range	.4V to 2.4V
Duty cycle range of PWM output	11% to 73%
Resolution of resultant duty cycle	0.017%

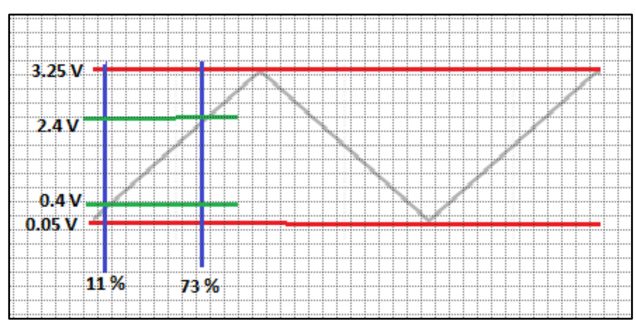


Figure [3]

VII. MPPT USING COMMERCIAL INTEGRATED CIRCUITS

In this approach, we implement the system where the MPPT algorithm (P&O) will be running in the dedicated Integrated circuit(IC) available commercially. Next requirement is that the IC should track maximum power point efficiently (settling time should be minimum) in changing irradiance too.

Table [6]. Comparison of ICs studied

IC	Manufacturer	Input Voltage range (V)	Input Current range (A)	Why was it rejected
BQ24650	Texas Instrument	5 - 28	0.8	Designed for Constant external conditions & Low Voltage/current range
LT3652	Linear technology	4.95 – 34	2	Focuses mainly on Battery charging profile
SPV1040	STM electronics	0.3 -5.5	1.2	Low Current range
LT8490	Linear technology	6 - 80	-	Minimum voltage out of required range

Texas instruments' SM72442:

Features:

- 5 V supply voltage
- I2C interface for communication
- Switching frequency of 220 kHz
- Achieves MPP in 0.01s

It requires external quad MOSFET driver, to drive the two half bridges of the full bridge converter. The driver chosen is LTC1156 which is quad driver and operates at 5V. To sense the input and output current Texas instruments' INA225 was chosen. However, the challenge with this IC is the low switching frequency which results in larger component size.

VIII. CONCLUSION

The MPPT system developed for the EPS of COEP Satellite Initiative's second mission is designed and optimised for the expected environmental parameters such as irradiance and temperature while orbiting in LEO. The trade-offs between many parameters such as the PWM resolution, converter switching frequency, voltage ripples, efficiency etc. is taken into consideration for the system design. Different approaches for realizing MPPT system such as analogue, digital and hybrid are taken into consideration while designing. The overall effort has materialized into an optimised, scalable battery charger module with MPPT capability which is designed as per the mission requirements. The system developed can be easily adopted for any other EPS as per the specific requirements with some minor changes.

IX. REFERENCES

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