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Solar Charge Controller

Buck Converter Topology

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Abstract—**This paper focuses on the salient features to be considered while designing a highly efficient buck converter. It also focuses on efficient algorithms implemented in order to extract maximum power voltage from the solar panel.**

KEYWORD: MPPT, Buck Converter, SR, ADC, MOSFET,PWM

I. INTRODUCTION

Energy is the biggest crisis the world is facing today. Depleting conventional sources of energy such as fossil fuels brings the need to explore alternate sources of energy. Solar is one of the most abundant source of alternate energy in the world. Utilization of this energy with a high efficiency without compromising on cost is the challenge we are facing today. However a solar panel available today has an efficiency in the range of only 12% to 15%. Hence it is very essential to design a power converter with a very high efficiency for utilization of this available energy with minimum losses. Such a converter must also be controlled so as to charge a battery efficiently. The main function of the charge controller is to manage the electrical output of the solar cell and to control the voltage and current for efficiently charging a battery. The converter circuit designed is a buck circuit which is implemented for high efficiency. The switching converter is controlled with the help of a microcontroller to perform efficient computational algorithms like MPPT, PWM and ADC conversions, thus charging the battery efficiently.

II. ALGORITHM FOR SOLAR CHARGE CONTROLLER

A. Perturb and Observe Method

This is one of many MPPT (Maximum Power Point Tracking) algorithms implemented, which manipulates the solar panel to operate at the maximum power voltage at every instant. The controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. This is called the perturb and observe method and is most common, although this method can result in oscillations of power output. It is also referred to as a *hill climbing* method, because it depends on the rise of the 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. The algorithm results in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

The solar panel selected is rated at 260 Watts with an open circuit voltage of 38 Volts. The power converter however is designed for charging a 24 volt battery. The output of the solar cell is constantly varying as it depends on the incident sunlight; this brings the need for a controlled closed loop converter.

B. Need for Microcontoller

The microcontroller enables us to control and vary a number of parameters for efficient charging of the battery. A number of features to protect the charge controller system are implemented with the help of the microcontroller. The controller varies the duty cycle of the MOSFETs with the help of ADC channels. There are numerous events happening in the system and these have to be scheduled sequentially for efficient operation. The battery status has to be monitored at regular intervals in order to know the battery level; if it is low the microcontroller sends signals so that the solar panel charges the battery. The microcontroller also has another important function of protecting all the equipments, like in case of short circuit at any point, the microcontroller should be able to sense the fault and provide warning message to the user so that he is aware of it. The microcontroller should be able to communicate actively with the user through the blinking of LED or through a LCD display.

The microcontroller chosen is highly efficient and has a 32 bit CPU timer, it has 10 MHz in built oscillator which can be scaled up to 90 MHz. It uses the Harvard bus architecture which is very advantageous as parallel communication is possible. It has the atomic operation feature; these are a set of utmost important statements which cannot be interrupted even in case of interrupts. Also it has very fast interrupt response and 54 programmable GPIO pins. It is code efficient in C, C++ and even assembly language programming. It also has little Endian feature which makes data storage easier. It works on a 3.3 volts supply and has two serial communication interface modules (SCI, UART). It has 16 PWM channels and three 32 bit timers.

III. NEED FOR EFFICIENT BUCK CONVERTER

The buck converter is essential for providing efficient power conversion. Firstly, the output of the solar cell can vary from 28 volts to 40 volts depending on the intensity of light incident on it. However for charging a battery we require only 12 or 24 Volts. To charge the battery efficiently a controlled operation is necessary to enhance the quantity of charge being pushed into the battery for a given voltage. To achieve this, we need a highly efficient power handling technology which converts panel voltage into battery voltage with negligible losses.

A. Design Specifications

Based on the initial analysis, the following specifications were chosen and the buck converter was designed based on the traditional topology.

- 260 watt solar panel
- Charging a battery of 24 V
- Allowing a current ripple of 20% and a voltage ripple of 2%.
- Switching at a frequency of 100 KHz

The design of the converter can begin once these parameters have been decided. First we need to consider the topology of

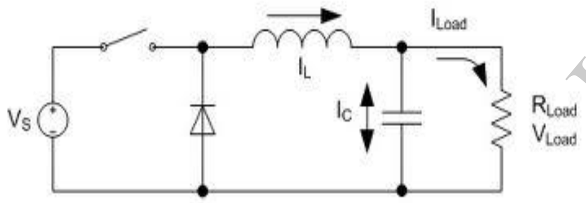

Fig 1 Buck Converter topology the converter we will be using.

The figure above shows the topology of a typical buck converter with the MOSFET depicted as a switch which operates at a frequency of 100 KHz.

The inductor is present to ensure that the current flowing through the circuit is continuous. Inductor is also responsible for maintaining the current ripple within the specification limits.

The value of the inductance is selected from the allowed value of current ripple. Since we have decided to allow a 20% ripple current, our design for the inductor will be as follows:

Output power (Po) = 260W

Output voltage (V) = 24V

Current (I) = (Po/V) = 260/24 = 10.84 A

Allowed Ripple current = 0.2*I = 2.166A

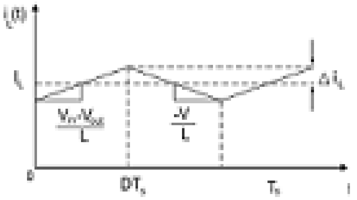

Fig 2 Inductor ripple current

The graph shows the inductor current profile. 2*ΔI being the value of current ripple of 2.166 amps

The inductance L of the converter is given by,

$$L = e*(\Delta I/\Delta t) \qquad (1)$$

Here, ‘e’ is the voltage associated with the inductor during off cycle or on cycle. e = (Vin – V).

The value of minimum capacitance C can be calculated by calculating the total charge over one complete cycle of ripple current.

The charge in a capacitor is given by

$$C = (\delta I*Ts)/ (8\delta V) \qquad (2)$$

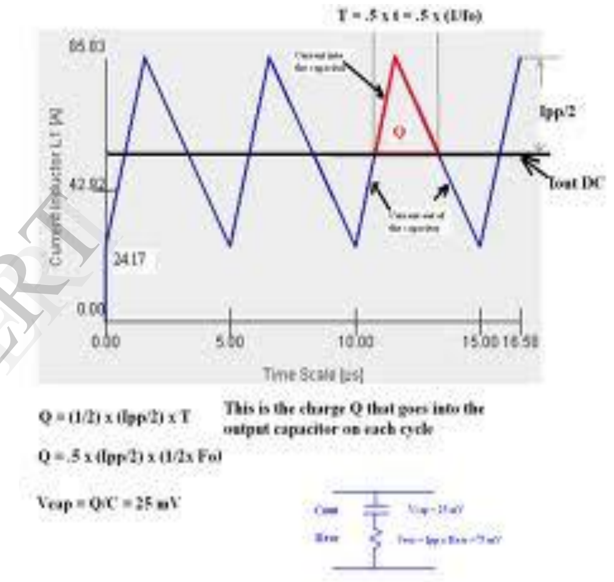

Fig 3 Capacitor ripple current

From equation (2) we get the minimum value of capacitance required to maintain the voltage ripple due below 2%.

But however the actual value of ripple is due to equivalent series resistance [ESR] associated with the capacitor. The value of ESR must be selected so as to not let ripple voltage go beyond 2%.

$$\delta V = Irms*ESR \qquad (3)$$

But we need to modify the above topology of the buck converter to optimize our design for high efficiency.

If an efficiency as high as 98% needs to be realized, then we need to select a schottky diode with a very low on-state resistance, this will be very costly. Hence there arises a need to look at the concept of synchronous rectification.

B. Synchronous Rectification

In a continuing effort to increase the density and speed and to decrease power consumption of data-processing circuits, their power supply requirements are being reduced from 5V to 3.3V. The increased availability and use of 3.3-V logic ICs have spurred significant development and research efforts in the area of low-voltage power supplies. A number of approaches with different goals and levels of complexity have been taken in these designs. They range from simple dc/dc buck-converter add-on modules that convert outputs of existing power supplies to the modules that convert outputs of existing power supplies to the required low voltage, to more sophisticated ac/dc converters with synchronous rectifiers (SRs).

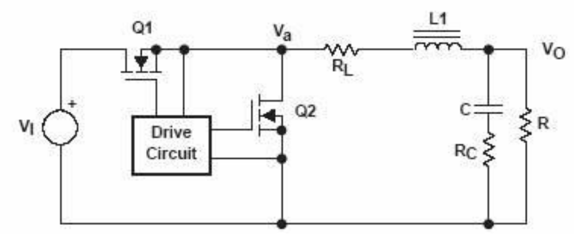

Fig 4 Synchronous Buck Converter Topology

Ideally, it would be desirable that the resetting time be equal to the off-time of the primary switch. Then the output current would freewheel through the SR for the entire off (freewheeling) time. The objective of this section is twofold. The first is to theoretically determine the limit of efficiency improvements that can be obtained from SRs. This limit is primarily a function of the output voltage, output current, on-resistance of the SR, and the forward-voltage drop of Schottky rectifiers replaced by SRs. The second objective is to compare conversion efficiencies of control driven SRs with those of different self-driven SR implementations. Specifically, performance comparisons of the forward converters with RCD-clamp and active-clamp reset are made.

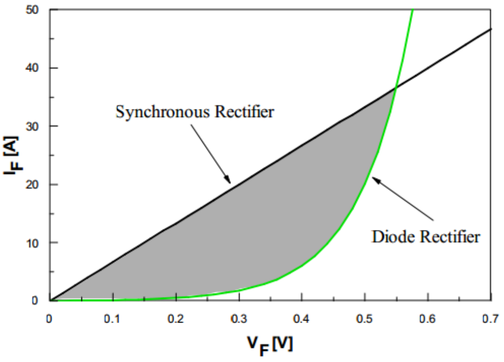

Fig 5 Forward-voltage comparison between synchronous rectifier and diode rectifier. Area has conduction loss saving by using synchronous rectifiers.

Hence by selecting suitable MOSFET we can limit the losses in the buck converter to less than 5 Watts for a 260 Watt panel. However extreme care must be taken to time the dead band accurately and synchronizing the switching accurately. While having too small a dead band can short the entire circuit, having too large a dead band will force freewheeling to happen through the reverse diode of the MOSFET rather than the MOSFET itself. This in turn would defeat the purpose of synchronous rectification.

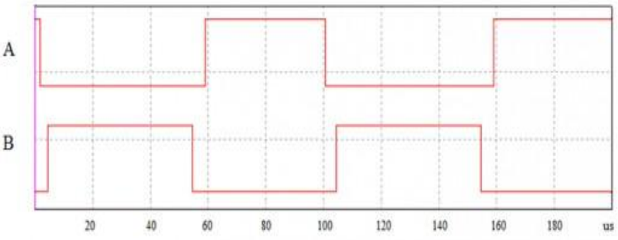

Fig 6 Pulses given to the MOSFETs

The pivotal modules of the system are the ADC interface and PWM controller. When the sunlight is incident on the solar panel, it absorbs this energy and converts it into electrical energy and sends it to the ADC module. The ADC then converts it into digital pulses and gives it to the microcontroller. The microcontroller receives these pulses and processes them and then varies the duty cycle of the PWM module appropriately and hence the output voltage changes accordingly and pushes maximum possible current to the battery for charging. If the solar panel is directly connected to the battery, over voltage might damage the battery.

IV RESULTS AND CONCLUSION

The efficiency aimed to achieve is generally not reached by majority of the converters in the market today. In the model, the duty cycle of MOSFET is varied automatically using closed loop control. This eliminates the need for manual intervention to change the duty cycle.

Duty Cycle Set: 58% Duty Cycle measured: 52.84%
MOSFET Temperature: 65 degree Celsius

Input Voltage(V)	Input Current(A)	Input Power(W)	Output Voltage(V)	Output Current(A)	Output Power (W)	Efficiency (%)
30	4	120	23.68	4.87	115.7	96.57
32.13	4.3	138.17	23.813	5.67	135	97.72
34	4.5	146.5	23.723	6	142.9	97.56
36.3	4.8	174.3	23.748	7.17	170.4	97.74
38.2	5	191.0	23.845	7.85	187.3	97.82

Fig 6 Converter Closed Loop Testing results

The solar charge controller was successfully designed and tested. For testing purposes, a programmable DC power supply was used instead of a solar panel. A converter efficiency of close to 98% was achieved after closed loop control which was the initial target set. An OVP limit had to be set on the supply, so that MPPT could be implemented over a small range.

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