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DESIGN & IMPLEMENTATION OF SOLAR FED INTENSITY CONTROLLED STREETLIGHT

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ABSTRACT

SPV based LED Streetlight has advantages over other conventional lighting systems as no power conversion is needed. LED work on DC and energy optimization is possible by controlling the duty cycle of the LED driver. The components of Solar Fed LED Street lighting system are SPV array, MPPT, dc-dc converter and battery unit. In this paper, the intensity of solar fed Street light is controlled from traffic hours to non-traffic hours which results in saving the electricity consumption. A hybrid street light model is also designed and developed. The simulation studies are performed in Matlab-Simulink environment.

I.INTRODUCTION

Solar PV is a renewable source of energy accessible all over the world but in Direct Current (DC) form. Standalone SPV system is very advantageous as compared to conventional grids especially for dc loads since there is no need to convert from ac to dc, which results in an increase in efficiency of the system. SPV based streetlight is one of the examples of Stand-alone PV system [1]. Light emitting diodes (LEDs) are becoming more popular in lighting applications because they exhibit high intensity or luminous with low power consumption and also, they work on DC effectively [2]. This makes PV based street lighting using LEDs a very attractive and viable possibility. The quantity of power developed by a SPV system is dependent on the solar irradiance so by sensing irradiance, energy management between SPV, battery and load can be controlled. This work highlights the energy efficient SPV street lighting system using LEDs through intelligent algorithm interface for energy management between SPV panel, Battery and Load. Also the amount of energy used by LED load is controlled by controlling its intensity during traffic hours and low traffic hours. So, the proposed SPV based LED streetlight can be operated with adequate solar charging with optimum energy consumption. Further, a PV hybrid LED street lighting system is also designed in this paper.

In recent years, there has been a growing emphasis on sustainable and energy-efficient solutions to address the global energy crisis and reduce the environmental impact of urban infrastructure. One notable application of this ethos is the design and implementation of solar-fed intensity-controlled streetlights. This innovative approach integrates solar energy harvesting technology with intelligent intensity control mechanisms to optimize the efficiency of street lighting systems. By harnessing the power of the sun, these streetlights not only contribute to the reduction of carbon footprints but also offer a reliable and cost-effective alternative to traditional grid-dependent lighting systems.

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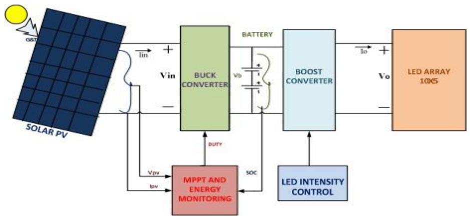

A SPV system of a capacity of a 200W peak with an output voltage and current of 39V & 5.20A is source of supply for the lighting system. Each street light is made of an array of 10x5 LEDs. Each LED is of 1W rating and has forward voltage of 2.9V. Solar PV is designed to produce the output voltage of 39V; a buck converter with MPPT is used to step down the SPV voltage to 24V for charging the battery. A Liion battery having a capacity of 24V has been used for storing the energy of SPV system during daytime. The battery is charged in daytime and discharged during night through the LED array. The battery capacity is selected such that even if there is cloudy and rainy climate for consecutive three days, the battery will supply electricity to streetlight. During high traffic hours i.e. from evening dusk to midnight 12:00 AM, the LED lamp is planned to glow bright for 100% intensity and during non-traffic hours i.e. after midnight the LED lamp brightness will be reduced down to 50%. The closed loop boost converter has been utilized to control the brightness of the LED lamp.

II. BUCK CONVERTER

A buck converter (step-down converter) is a DC-to-DC power converter which steps down voltage (while stepping up current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) typically containing at least two semiconductors (a diode and a transistor, although modern buck converters frequently replace the diode with a second transistor used for synchronous rectification) and at least one energy storage element, a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).

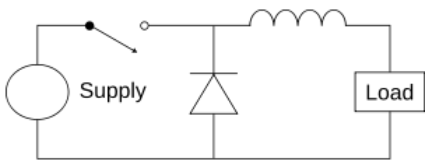

Fig. 1: Buck converter circuit diagram.

Switching converters (such as buck converters) provide much greater power efficiency as DC-to-DC converters than linear regulators, which are simpler circuits that lower voltages by dissipating power as heat, but do not step up output current.[2]Buck converters can be highly efficient (often higher than 90%), making them useful for tasks such as converting a computer's main (bulk) supply voltage (often 12 V) down to lower voltages needed by USB, DRAM and the CPU (1.8 V or less).

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when the switch is open (arrows indicate current according to the direction conventional current model).

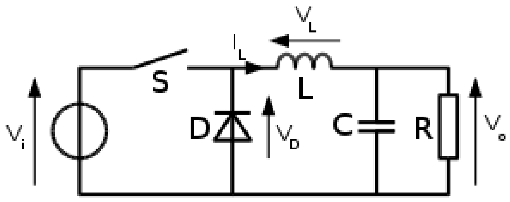

Fig. 3: Naming conventions of the components, voltages and currentf the buck converter.

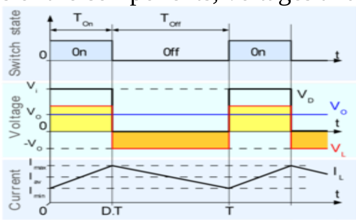

Fig. 4: Evolution of the voltages and currents with time in an ideal buck converter operating in continuous mode.

The basic operation of the buck converter has the current in an inductor controlled by two switches (usually a transistor and a diode). In the idealised converter, all the components are considered to be perfect. Specifically, the switch and the diode have zero voltage drop when on and zero current flow when off, and the inductor has zero series resistance. Further, it is assumed that the input and output voltages do not change over the course of a cycle (this would imply the output capacitance as being infinite).The conceptual model of the buck converter is best understood in terms of the relation between current and voltage of the inductor. Beginning with the switch open (off-state), the current in the circuit is zero. When the switch is first closed (on-state), the current will begin to increase, and the inductor will produce an opposing voltage across its terminals in response to the changing current.

This voltage drop counteracts the voltage of the source and therefore reduces the net voltage across the load. Over time, the rate of change of current decreases, and the voltage across the inductor also then decreases, increasing the voltage at the load. During this time, the inductor stores energy in the form of a magnetic field. If the switch is opened while the current is still changing, then there will always be a voltage drop across the inductor, so the net voltage at the load will always be less than the input voltage source.

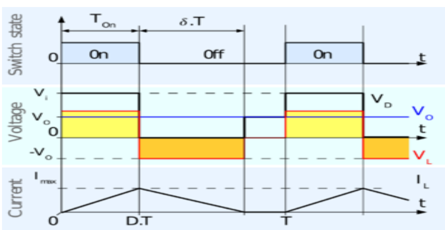

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Fig. 5: Evolution of the voltages and currents with time in an ideal buck converter operating in discontinuous mode.

In some cases, the amount of energy required by the load is too small. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle (see figure 5). This has, however, some effect on the previous equations.The inductor current falling below zero results in the discharging of the output capacitor during each cycle and therefore higher switching losses. A different control technique known as Pulse-frequency modulation can be used to minimize these losses.

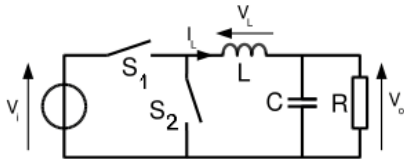


Fig. 8: Simplified schematic of a synchronous converter, in which D is replaced by a second switch, S_2.

A synchronous buck converter is a modified version of the basic buck converter circuit topology in which the diode, D, is replaced by a second switch, S_2. This modification is a tradeoff between increased cost and improved efficiency.

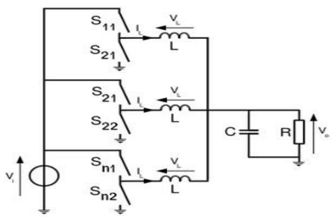
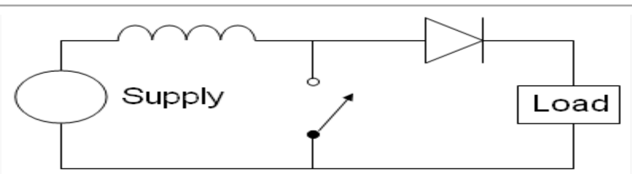


Fig. 9: Schematic of a generic synchronous n-phase buck converter.

This type of converter can respond to load changes as quickly as if it switched n times faster, without the increase in switching losses that would cause. Thus, it can respond to rapidly changing loads, such as modern microprocessors.

III. BOOST CONVERTER

A **boost converter** (**step-up converter**) is a DC-to-DC power converter steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage



The basic schematic of a boost converter. The switch is typically a MOSFET, IGBT, or BJT.

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element, a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).

power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converterwith an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage. Since power ($P = VI$) must be conserved, the output current is lower than the source current.

An unregulated boost converter is used as the voltage increase mechanism in the circuit known as the 'Joule thief'. This circuit topology is used with low power battery applications, and is aimed at the ability of a boost converter to 'steal' the remaining energy in a battery. This energy would otherwise be wasted since the low voltage of a nearly depleted battery makes it unusable for a normal load. This energy would otherwise remain untapped because many applications do not allow enough current to flow through a load when voltage decreases. This voltage decrease occurs as batteries become depleted, and is a characteristic of the ubiquitous alkaline battery. Since the equation for power is ($P = V^2/R$), and R tends to be stable, power available to the load goes down significantly as voltage decreases.

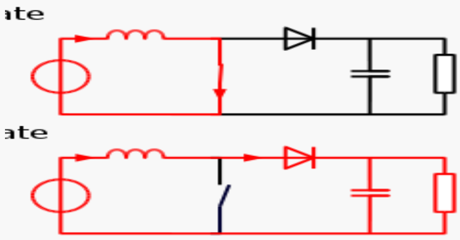

Fig. 2: The two configurations of a boost converter, depending on the state of the switch S.

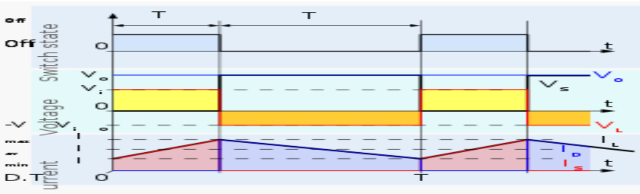

Fig. 3: Waveforms of current and voltage in a boost converter operating in continuous mode.

$$\Delta I_{L_{On}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L}V_i$$

Therefore, the variation of I_L during the Off-period is:

$$\Delta I_{L_{Off}} = \int_{DT}^{T} \frac{(V_i - V_o)\, dt}{L} = \frac{(V_i - V_o)(1-D)T}{L}$$

As we consider that the converter operates in steady-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in the inductor is given by:

$$E = \frac{1}{2} L I_L^2$$

Discontinuous mode

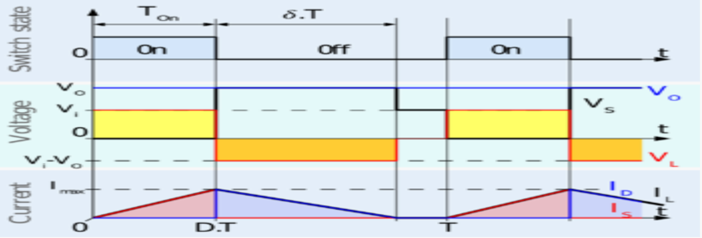

Fig. 4: Waveforms of current and voltage in a boost converter operating in discontinuous mode.

As the inductor current at the beginning of the cycle is zero, its maximum value $I_{L_{Max}}$ (at $t = DT$) is

$$I_{L_{Max}} = \frac{V_i DT}{L}$$

During the off-period, I_L falls to zero after δT :

$$I_{L_{Max}} + \frac{(V_i - V_o)\,\delta T}{L} = 0$$

Using the two previous equations, δ is:

$$\delta = \frac{V_i D}{V_o - V_i}$$

The load current I_o is equal to the average diode current (I_D). As can be seen on figure 4, the diode current is equal to the inductor current during the off-state. Therefore, the output current can be written as:

$$I_o = \bar{I_D} = \frac{I_{L_{max}}}{2}\delta$$

Replacing I_{Lmax} and δ by their respective expressions yields:

$$I_o = \frac{V_i DT}{2L} \cdot \frac{V_i D}{V_o - V_i} = \frac{V_i^2 D^2 T}{2L\,(V_o - V_i)}$$

Therefore, the output voltage gain can be written as follows:

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2 L I_o}$$

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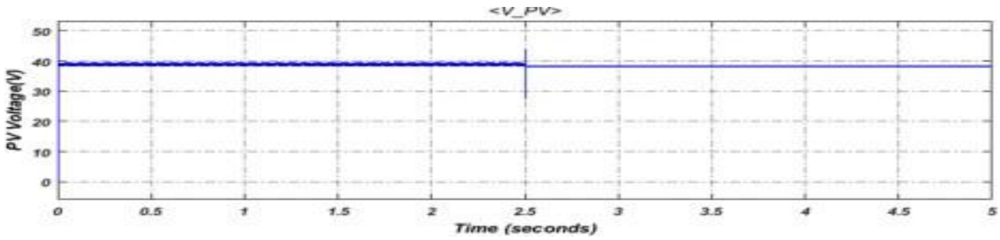
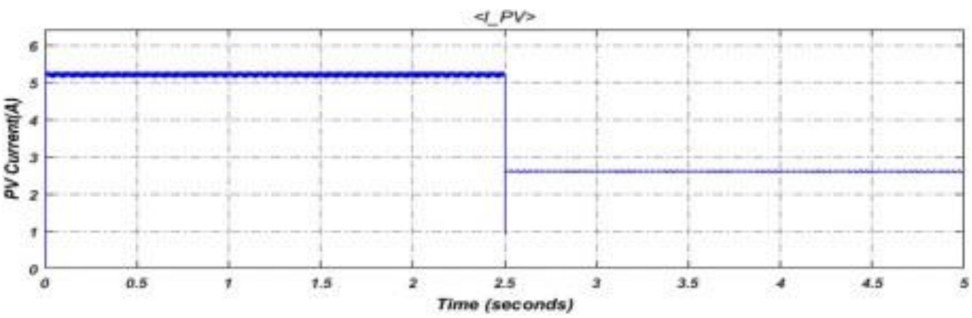
IV. SIMULATION RESULTS

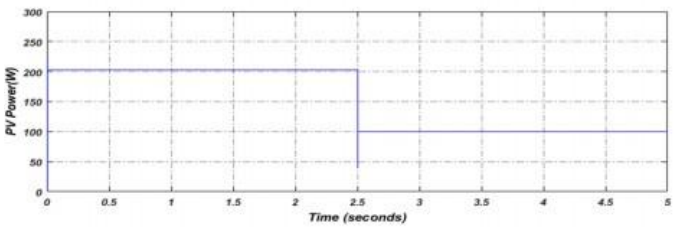
The developed scheme has been modelled using MATLAB-SIMULINK software. All the parameters have been designed using the above calculated values. The LED lamp load is modelled as simple series resistance of 0.823Ω with a battery.

As during the day the solar irradiance varies, so to analyze the performance of the system, the battery charging is performed for two solar irradiations i.e. 1000W/m2 and 500W/m2 . The Power, Voltage and Current graph of solar panel for both irradiance is shown in fig.5, 6 & 7 respectively. As is clear from fig, that at 1000W/m2 the maximum power is 200W and for decreased irradiance of 500W/m2
i.e. after 2.5 sec of simulation time the maximum power is reduced to 100W. The battery parameters i.e. SOC, voltage and current are shown in fig.8, 9 & 10 respectively.



When solar is not available, the battery is supplying power to the LED lamps as shown in fig.11,12. From dusk to midnight, the LED output current and voltage is 1.75A and 29 V respectively, so the power yield at the output is approx 50W. After midnight, as the traffic becomes very less so intensity of LED light can be decreased by controlling duty cycle of boost converter to save electrical energy i.e. from midnight to 6:00AM. It is shown in simulation after 2.5 sec correspondingly the LED output current and voltage is change to 0.86A and 27.8 V respectively, so the power yield at the output is approx 24W. As it is clear from the results that the approximately 50 % of the energy is saved during the non traffic hours.





V. CONCLUSION

The two models of smart solar LED street lighting are successfully designed and implemented. Based on the Model calculation and simulink results it has been observed that intensity control of LED has benefits such as less energy consumption and battery can work more efficiently giving higher duration of backup than compared to the streetlight which is working without any intensity control. Further a PV hybrid system is designed which can continuously under any weather conditions.

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