



Off-Grid Solar Based Power Generation

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Off-Grid Solar Based Power Generation

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Abstract—In the 21st century electricity is an essential part of life. There are some villages which are still deprived of this facility. This is due to the remote demographical location of these places. This paper proposes a design for a solar based Off-Grid system which will cater to the needs of such places, and the energy generated will be utilised efficiently. This system will help people to migrate away from non-renewable resources such as kerosene which is used to light the house.

Keywords— charge, booster, inverter, PWM, H4, H6, transformer less.

I. INTRODUCTION

India is a vast country. People in India are preponderantly living in villages. There are about 649481 villages in India. Such villages can be classified in terms of different demographic terrains, for e.g. dense forest, plain, etc. Few of these villages still lack access to electricity. It is difficult to lay transmission line in villages due to the difficult terrain. People in these villages mostly use kerosene lamp. As we know the kerosene is a non renewable source of energy. The solar based system is an effective solution to this problem.

The proposed design for a solar energy system [1] is targeted for deployment in villages where regular transmission lines are difficult to lay. This system will have a Photo-Voltaic (PV) [2] cell which will generate electricity and using charge controller it will charge the battery. Booster circuit will help to convert 24V to 250V. The inverter circuit will be used to convert the boosted DC to AC. Initial cost of system is high due to the cost of the PV cell and battery but operational cost is very less. Government of India offers a 30% subsidy and within 3-6 years the cost is recovered. There is zero CO₂ emission. On the other hand, off-grid applications do not require the infrastructure related to transmission [3]. Our design is entirely transformer-less which reduces the size and inductive losses.

II. SYSTEM DESIGN

The block level system is illustrated in Fig. 1. The description of the sub-units is as follows:

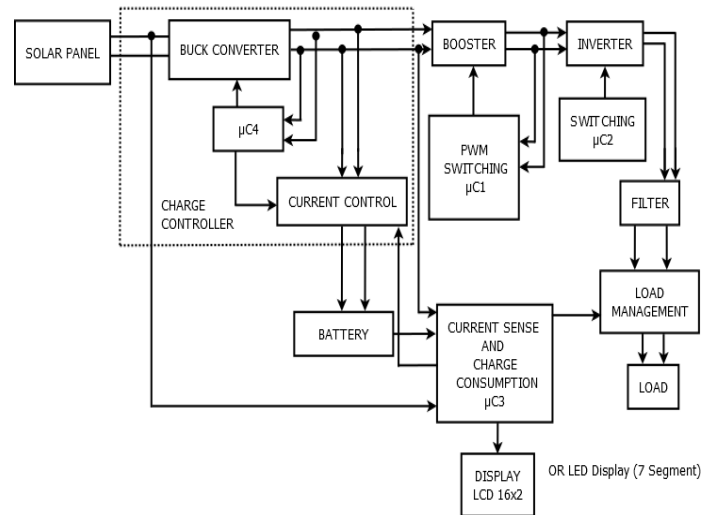


Fig.1. System block diagram

A. Charge Controller

Charge controller as shown in the Fig.1 consists of a simple buck circuit which converts higher voltage to lower voltage, with increase in current.

$$V_o = V_i - L \frac{di}{dt} \dots\dots\dots (1)$$

$$D = \frac{V_o}{V_i} \dots\dots\dots (2)$$

Inductor value, switching frequency and duty cycle of the buck decides the voltage and current at the output as expressed in (1) and (2). Normally the output voltage of the panel is higher than the required value, to bring it back to its required value, buck circuit is used which also ensures that current will not flow back towards the panels at night [4]. Normally 10% of the rated current of the battery is used to charge it. Since the current sourced by the solar panels depends on the intensity of the light falling on the panels, it varies over the day as shown in the Table.1. Charge controller will maintain a constant charging current for battery. When input current is higher than the battery charging current, charge controller will allow constant charging current to flow towards the battery and remaining current will flow towards the booster. Hence booster will take less current from battery. If the current from PV sourced is lower than the charging current then the entire current will be utilised to charge the battery and booster circuit will draw entire current from battery.

Time	Voltage(OC) V	Current(SC) A
9 am	144.1	1.56
10 am	143.9	2.28
11 am	144	2.89
12 pm	142	3.10
1 pm	143.05	3.89
2 pm	143	3.05
3 pm	146.7	2.895
4 pm	148.2	1.05
5:30 pm	148.50	0.131

TABLE.1. Solar panel current and voltage variations during the day.

B. Booster

A boost converter is a DC to DC step up converter [5] that steps up voltage while stepping down current at its output from its input. The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. However, the input and the output power remains the same. Hence at the output side voltage increases while the current decreases. Thus, the source should be able to supply sufficient current for proper operation of the circuit. A schematic of a booster stage is shown in Fig. 2.

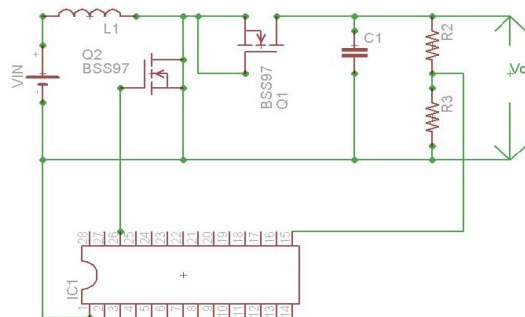


Fig. 2. Schematic diagram for Booster Circuit.

The frequency and duty cycle of the switching signal (SS) applied to MOSFET (MOS) Q2 decides the output voltage as per (3) and (4). When the switch is ON, the blocking diode prevents the capacitor charged during OFF state to discharge through the switch, thus the charge is retained across capacitor. The switching action must be fast enough to prevent the capacitor from discharging too much and maintain constant voltage at the output. The output voltage of the booster is given by the equation (3).

$$V_o = V_{in} + L \frac{di}{dt} \quad \dots\dots\dots (3)$$

The equation for the relation of input and output voltages is given as (4).

$$\frac{V_o}{V_{in}} = \frac{1}{1-D}, \quad \dots\dots\dots (4)$$

where D is the duty cycle of the switching signal. The (3) shows that the output voltage is always higher than the input voltage as shown in Fig.2 (as the duty cycle goes from 0 to 1, as indicated in (4)) and that it increases with D, theoretically to infinity as D approaches 1. Fig. 3 shows the practical setup of the booster circuit which boosts the 5V input to 30V output.

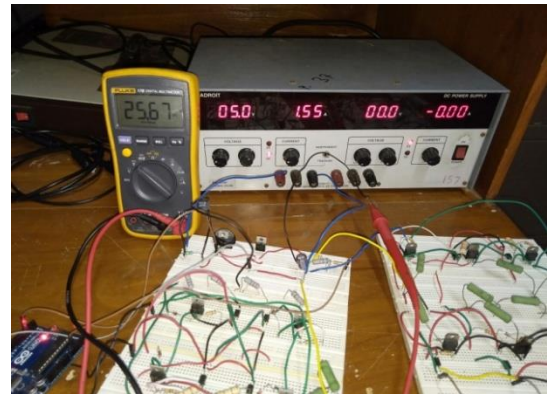


Fig.3. Boosted output DC voltage of Booster Circuit.

C. Inverter

Inverter is used to convert DC voltage from booster to an alternating AC voltage at the output load (R8). Inverter can be designed in two configurations, with and without transformer.

1) Transformer based inverter does not require a separate booster stage as transformer itself can be used as a booster in step up mode and simultaneously can be used for generating AC voltage from DC. However, such a circuit tends to produce a lot of heating and losses which might lead to decreased efficiency. It also makes the circuit bulky and costly.

2) Transformer-less inverter design [6] as shown in Fig. 4 has higher efficiency, low weight, size and less losses. This circuit requires an additional protection to output load to provide isolation from short circuits.

Our focus is to design a transformer-less inverters (H4 and H6 configurations). The four main requirements for the inverter design are:

- 1) Switching signal.
- 2) Source to provide switching signal.
- 3) Grounds of top and bottom MOSFETs (MOS) need to be isolated from one another.
- 4) Isolation between microcontroller and the line current.

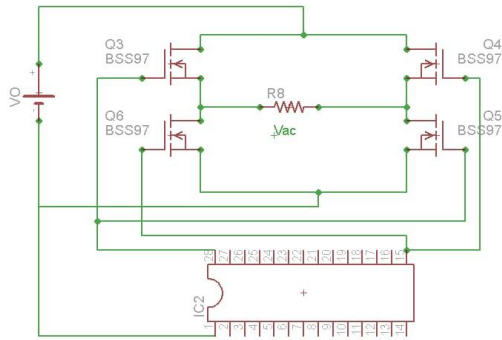


Fig.4.Schematic diagram for inverter circuit.

Microcontroller output cannot be directly used to provide switching signals to the MOS as it would lead to shorting of bottom two MOS. There are two alternatives to overcome the above problem, one is to use an Opto-coupler (OC) or a pulse transformer(PT) both of which satisfies the above 4th requirement. Circuit with OCs are normally smaller in size, cheaper and easy to design as compared to pulse transformer, but this design requires an additional resistor (R) in series with the line current which leads to decrease in efficiency of the system and has a disadvantage of low switching speeds.

PT design [6] can prevent the above problem of efficiency and switching speed but the designing of PT and triggering of MOS as per requirement is a challenge by itself. PT provides output in pulses hence an additional circuit is required to convert these pulses into square wave. PT consist of 1:1 turns ratio and number of primary turns are given by (5) .

$$Np = \frac{V \cdot T}{\Delta B \cdot Ae} \dots\dots\dots (5)$$

Average power delivered to the output load can be controlled using the nature of the switching signal (SS) [7]. Switching Signal can either be a full 50Hz/60Hz square wave as shown in Fig. 5 or a PWM SS of high frequency with a fundamental frequency of 50Hz/60Hz as shown in Fig. 6.

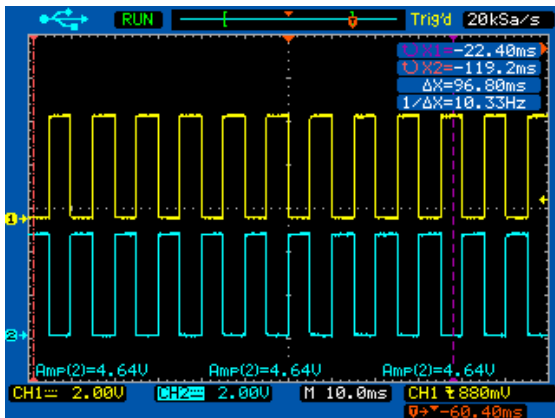


Fig.5. Square wave switching signals (50Hz).

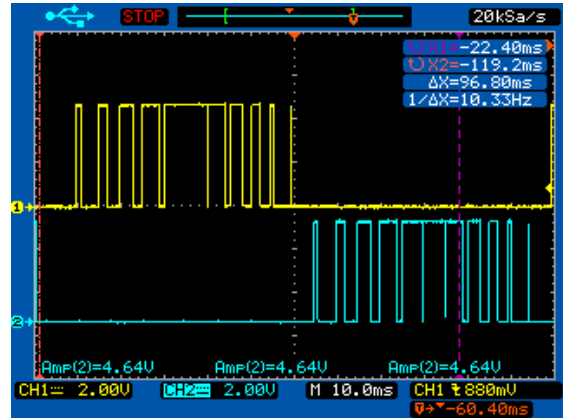


Fig.6. PWM wave switching signals (50Hz).

D. Load management

In our approach, ideal case scenario is taken into consideration, where the two rooms are kitchen and hall. Each of the two rooms will be equipped with one lamp and a fan. The work of the main microcontroller is to monitor the battery level and there will be auxiliary microcontrollers in both the rooms which will be used to communicate with the main microcontroller. The control line will be used for the transmission and reception of data packets between main and auxiliary micro-controllers. The control line will also be used to send acknowledgements between main and auxiliary controllers. Relays will be used to switch the loads ON or OFF. The idea is to switch ON or OFF the load as per predefined priorities which are in turn dependent on the battery voltage. When the battery is fully charged, the main microcontroller will send the signal to both the auxiliary microcontrollers to switch ON their loads. Once the auxiliary microcontroller receives this signal, they will send acknowledgement to the main microcontroller and perform the necessary action. The main microcontroller senses the voltage of the battery and thus gives command to either of the auxiliary microcontrollers to turn ON or turn OFF the load, depending upon the priorities set. The reverse switching action takes place on the equipment as battery voltage goes on increasing as charging circuit charges the battery. This idea can be made automated by making the use of proximity sensors and temperature sensors. The equipments are switched ON or OFF by the respective room microcontroller depending on the human detected by the IR sensor and the temperature of the room by the temperature sensor. Appliances will be operated in both automatic and manual mode. The

model will work as such, every time the battery voltage reaches a certain value, the sensors in each room will detect the temperature and presence of a humans in the room.

III. DESIGN CALCULATIONS

It is necessary to consider the current requirements of the system along with the voltage. Suppose system is designed to provide a maximum(max) of 500 Watts output(o/p) with 230Vrms, hence the current required will be as per (4).

$$I = \frac{P}{V} \dots\dots\dots (6)$$

Therefore average current required is 2.17A. considering the ideal conditions in the absence of loses, booster should be able to supply max of 230V and 2.17A at its o/p that is 500W to the inverter. Now if the input (i/p) of the booster is supplied with 48V, it will be boosted to 230V at its o/p. Since the i/p and o/p powers of booster should remain same, i/p average current should be 10.41A as per (6). 10.41A is the average current, but the booster is supplied with a switching signal of particular frequency and its duty cycle varies. Suppose duty cycle is 50% than to achieve 10.41A average current, peak current(PC) which the battery should be able to provide is 20.82A as per (7).

$$\text{peak current} = \frac{\text{average current}}{\text{duty cycle}} \dots\dots\dots (7)$$

As the duty cycle decreases PC increases and vice versa. In order to avoid loading or short circuit, system must be designed with max supply current considering the practical circuit loses. Inductor value of booster is calculated using (8)

$$L1 = \frac{Vl}{di/dt} \dots\dots\dots (8)$$

From (3) and (8) Vl is calculated as 182V for V_o and V_{in} as 230V and 48V respectively. If the switching frequency is 100KHz and duty cycle is 50% then $L1$ comes out to be 45.5 uH using (8) and (9).

$$di/dt = \text{peak current} / \text{time period} \dots\dots\dots (9)$$

IV. OBSERVATIONS

A. Booster

The output voltage of the booster circuit was dependent on the load resistance as shown in table.2; hence a feedback using voltage divider

circuit was provided to the microcontroller. With the help of this feedback in the program, duty cycle of the SS was varied in accordance with the load variation to maintain a constant output voltage [9], [10].

Load resistance (ohms)	Duty cycle(%)	Output(V)	Input(V)
900	50	20	3.7
800	55	20	3.7
700	60	20	3.7
600	65	20	3.7
500	70	20	3.7
400	75	20	3.7
300	80	20	3.7
200	90	20	3.7

TABLE. 2. SS duty cycle and load resistance relation.

B. Inverter

The output waveforms of the inverter circuits with square wave SS and PWM wave SS are as shown in Fig. 7 and Fig. 8, respectively.

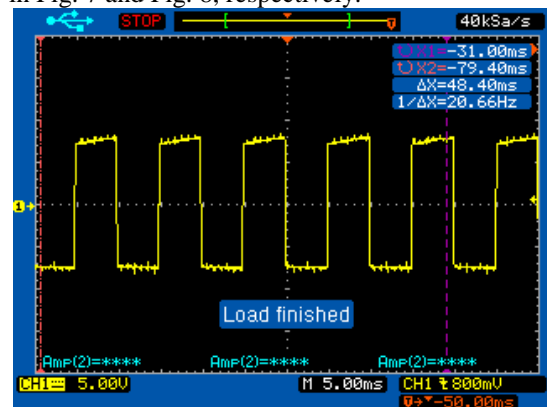


Fig.7. Output voltage with square wave SS.



Fig.8. Output voltage with PWM wave SS

V. RESULT

Practical setup for booster and inverter circuits was designed as shown in Fig.9 to verify the operation of both the circuits as per the design consideration.

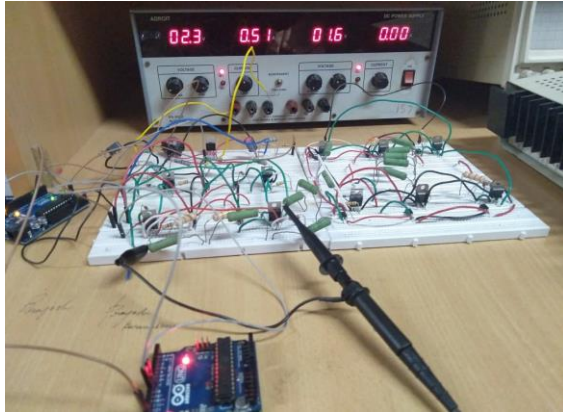


Fig. 9. Practical system setup.

The design values for the booster circuit are as shown in table.3.

Vin (V)	Vout (V)	Frequency(KHz)
5	30	100

TABLE.3.Booster design values.

Booster circuit was designed to boost the input voltage 6 times. Input voltage applied was 5V and the output obtained was around 30V. Feedback controlled booster output voltage was providing stable constant 30V output with negligible ripples. The design values for the inverter circuit are as shown in Table.4 and table.5.

Topology	Load(ohms)	Vin (V)	Vout (Vpp)	Freq (Hz)	Current drawn (A)
H4	500	30	51	50	1.21
H6	500	30	51	50	1.89

TABLE.4. Inverter design values for resistive load.

Topology	Load(ohms)	Vin (V)	Vout (Vpp)	Freq (Hz)	Current drawn (A)
H4	500	30	54	50	0.61
H6	500	30	53	50	1.1

TABLE.5. Inverter design values for inductive load in series with resistive load.

Inverter was providing a proper square wave output waveform of 50Hz and up to 54Vpp magnitude with 30V input. H6 circuit is capable of drawing more current compared to H4 circuit. H4 circuit requires less components compared to H6. Addition of inductive load decreases the current drawn by the system thereby increasing the efficiency and decreasing the wattage requirements of the system components. Use of PT inverter circuit provides higher efficiency as compared to OC circuit. PWM inverter switching delivers power to the load in terms of pulses, thus reducing the

average power delivered to the load with the same functionality as that with full square wave switching. Thus PWM switching reduces the power consumed by the system. PWM also helps in obtaining a proper sine wave output from square wave.

VI. CONCLUSION

The proposed circuit design for the Off-Grid solar energy system makes use of minimal number of inductors thus making it efficient in terms of space utilization and less energy losses. The circuit model is designed to provide 30V output from a 5V input with an efficiency of around 70%. However, simulations prove that for a design of 230V efficiency increases up to 96% which can further be increased using PT switching design. The efficiency and cost of existing systems in the market are directly related to each other, providing efficiencies from 80% to 96% with the cost variation of Rs. 50000/- to Rs. 100000/-, respectively, including maintenance cost.

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