Study of Electricity Demands of a Rural House

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***Abstract*—This paper discusses about the difficulty in rural electrification and aims towards providing a solution in the means of off-grid solar setup. A study of load calculation for a single rural house is conducted and accordingly its power requirements are stated. Based on the basic power requirements, calculation of Photovoltaic module size and the battery backup is estimated. Paper explains different ways to enhance the efficiency of solar panel. Powering rural houses using solar and with minimal requirement is the central idea of the paper. It also covers the cost estimation that will be required to design the similar setup.**

***Keywords*—Rural electrification, Solar panel, Photovoltaic module ,Maximum power point(MPP).**

I. INTRODUCTION

Rural electrification has been a major challenge for a country as big as India. Even though in the recent past the target of electrifying every village has been achieved, it hasn't powered every household in those villages.

The some households who are beneficiaries of the new connection are facing routine problem of load shedding or frequent power outages. There is a heavy infrastructural requirement in order to achieve the goal of uninterrupted power supply. In addition to that, problem arises due to geographical constraints of those villages. There are many hurdles that are needed to be crossed in order to fulfil the requirements of a comprehensive rural electrification. Especially in a Third World countries like India, there are geographical constraints due to which it becomes a cumbersome task to setup the power station.

Due to high proximity from urban enclosure and lack of proper communication infrastructure, the speed of reporting and deploying help during any kind of emergency tend to be slower. Unforeseen climatic conditions sometimes can cause more damage due to unpreparedness amongst the residents. One cannot deny the fact that, a villager faces many challenges in getting a new connection due to unnecessary bureaucratic interference. Another important factor that leads to misuse of electricity is by power thefts, which is a common sight in rural areas.

Under those circumstances, it is best to decentralise the way electricity is provided to rural households. One way to achieve that is by relying on solar panels which can provide sufficient output to power necessary appliances. It will not just be a clean source of energy but also will go down to make it affordable in the long run. Also, various renewable energy programs [5], have been launched by Indian government to promote rural electrification.

In the state of Goa, a typical Goan house is lit up for about 8 hours a day. Therefore if power is generated from solar panels, it will be sufficient to power any rural house for the same amount of time using LED lighting.Goa does not produce electricity of its own, it has to purchase from neighbouring states like Maharashtra.Normally, the coastal state experiences a long day, with a sunrise at about 6 a.m. while the sunset is at around 7 pm. Such amount of sunlight is sufficient to power rural home for as long as eight hours.

A. Load Calculation

List of things to be considered before choosing the type of off-grid solar system:

1. What is your monthly or daily electricity usage?
2. What is the solar panel output power according to the kind of appliances in your shelter?
3. What is the maximum budget you have for the same?
4. How to efficiently increase the solar power output from the panel using charge controllers?

Let us consider a rural home with 5 rooms such as Bedroom, Living room, Kitchen, Bathroom and Store room. The bedroom and living room lights are more frequently used and thus have 18 watt LED bulbs. The other 3 rooms use 9 watts LED bulbs. As in this setup, the less often used room may have bulbs with lower wattage. This helps in further reducing the size. This system can also be used along with grid system to reduce the electricity bill and also generate power on its own for additional usage.

TABLE I

LOAD CALCULATION FOR A RURAL HOME

Load	Wattage	Number	Total Power (Watts)	Hours
Bulb	18	2	36	8
Bulb	9	3	27	8
		Total	63W	

As we can see from Table I, a 18 watt bulb is used is used for approximately 8 hours,

$$18\, watts * 8\, hours = 144\, watt - hours$$

3 of such bulbs are used for 12 hours giving us an estimate as shown

$$2 * \ 144\, watt - hour = 288\, watt - hours$$
$$= 0.288kWH$$

Similarly, a 9 watt bulb is used for 8 hours,

$$9\, watts * 8\, hours = 72\, watt - hours$$

Considering 2 of such bulb used in a rural home gives,

$$3 * \ 72\, watt - hour = 216\, watt - hours$$
$$= 0.216kWH$$

The amount of power needed for the above requirements is given by,

$$Total = 0.288 + 0.216 = 0.504\ kWH$$

B. Solar panel and battery estimation:

The total amount of power need for required load is 504 WH. The average amount of sunshine received per day is approximately 4 hours. Thus the solar panel size is estimated as follows:

$$Solar\ panel\ size = \frac{504\ w}{4\ H} = 126\ watts$$

Roughly, 100 watts solar panel can serve the purpose. 100 watt, 12v solar panel costs around Rs.2000 in Indian market and the cost further reduces if the purchase is in bulk.

For the load requirements in table II, the battery backup is needed for 8 hours. The Ampere Hour (AH) rating of battery can be estimated as,

$$Battery\ (AH) = \frac{504\ w}{12V} = 42\ AH$$

A 30Ah battery costs around Rs.2500 in the Indian Market.

Charging current of the battery is given by 1/10th of its ampere-hour rating, therefore,

$$Battery\ charging\ current = \frac{1}{10} * 30 = 3\ A$$

As per the cost estimation of solar panel and battery size, the total off-grid solar subsystem costs about Rs.4500. This amount is one time installation amount.

C. Load Calculation on hourly basis:

Table II shows load calculation of 5 rooms: Bedroom, Kitchen, Bathroom, Living room, Storeroom. Bedroom and Living room are frequently used and thus have higher wattage bulbs. Load calculation on hourly basis is done.

TABLE II

LOAD CALCULATIONON HOURLY BASIS

Room	Load	Watts	6-8am	8-10am	10-12pm	12-2pm	2-4pm
Bedroom	LED bulb	18	N	Y	N	N	N
Living room	LED bulb	18	N	N	Y	N	N
Kitchen	LED bulb	9	N	Y	Y	Y	N
Bathroom	LED bulb	9	N	Y	N	N	N
Storeroom	LED bulb	9	N	Y	Y	N	N
TOTAL			-	$90WH$	$72WH$	$18WH$	-

Room	Load	Watts	4-6pm	6-8pm	8-10pm	10-12pm	12pm-6am
Bedroom	LED bulb	18	N	Y	Y	N	N
Living room	LED bulb	18	N	Y	Y	Y	N
Kitchen	LED bulb	9	N	Y	Y	N	N
Bathroom	LED bulb	9	N	N	Y	N	N
Storeroom	LED bulb	9	N	Y	N	N	N
TOTAL			-	$108WH$	$108WH$	-	-

The total amount of power needed for the above load is calculated as,

$$Total = 90 + 72 + 18 + 108 + 108 = 396\ WH$$

The table also shows the peaks hours when the power consumption is maximum. Duration between 12am-6am, no lights are being used. Few bulbs are used during day time and the maximum usage is after 7pm.

II. PHOTOVOLTAIC SYSTEM AND ITS CHARACTERISTICS

A. Photovoltaic system and its characteristics:

Solar panels also called as photovoltaic panels consists of number of solar cells typically 36, which convert solar energy into electrical form. Subsystems of an off-grid [2] setup are:

- Photovoltaic Module.
- DC-DC converter.
- A charge controller.
- Battery

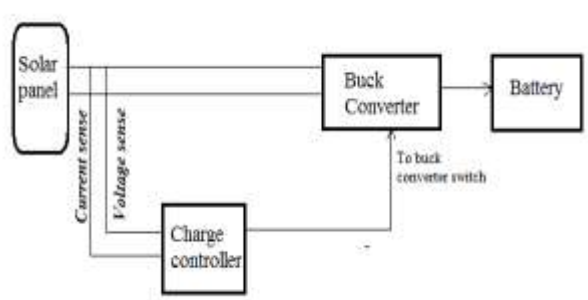

Fig.1. Block diagram of off-grid solar system

Specification of a 10 watt, 12v solar panel is shown in table III,

TABLE III
PV MODULE SPECIFICATION

Electrical	
Max Power Volts (V_{mp})	17.83 V
Max Power Current (I_{mp})	0.57 A
Open Circuit Voltage (V_{oc})	21.75 V
Short Circuit Current (I_{sc})	0.61 A

- **Max. Power Volts (Vmp)**is the voltage across the terminals of the solar panel when output power is maximum.
- **Max. Power Current (Imp)**is the current obtainedat the terminals of the solar panel when output power is maximum.
- **Open circuit voltage**(**Voc**) is the voltage across the terminals of the solar panel when they are open circuit.
- **Short circuit current (Isc)** is the current flowing when the terminals of the solar panel are short circuit.

B. Maximum Power Point Tracking:

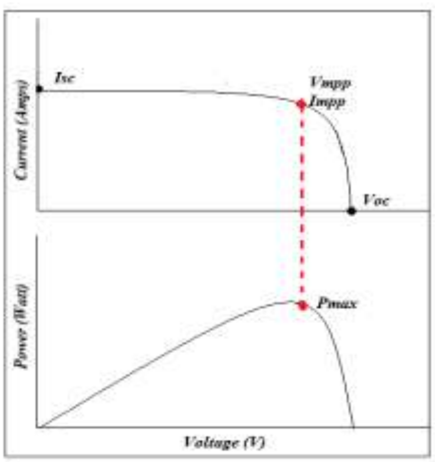

Fig.2 .Solar panel characteristics

Figure2 indicates the characteristics of a solar panel [1]. As the intensity of light from the sun and also the temperature is not constant all the time, the characteristics of solar panel vary accordingly. From the figure2, it is seen that there is a point on the curve where the power is maximum, known to be Maximum power point (MPP) [11]. At this point, the solar panel works at its highest efficiency delivering maximum power to the load. The microcontroller senses the input current and voltage and calculates the power.

C. Charge controller:

The solar panel has the ability to directly charge the battery however the problem arises when the voltage exceeds battery charging voltage limit. For a 12 V battery, maximum voltage for charging cannot exceed 14 volts. Any surplus in voltage might result in damaging the battery. Also the voltage from the solar panel is not always consistent. Even in peak sunshine hours, there are times where the total energy may not be transferred from solar panels to the battery. In such a case, the charge remaining in the solar cell is given out as heat which leads to ageing of the solar panel. In addition to that, battery may also get damaged if it is overcharged after achieving its full capacity.

In order to safeguard the battery under such circumstances, it is necessary to make use of charge controllers. The charge controller in this case is a microcontroller which controls the PWM output given to switch of buck type DC-DC converter. An algorithm (fig.3) known as perturb and observe (P&O) is used by microcontroller to reach this maximum point. P&O also called as hill climbing method works by comparing the newly calculated power with the previously sensed one and accordingly changing the duty cycle.

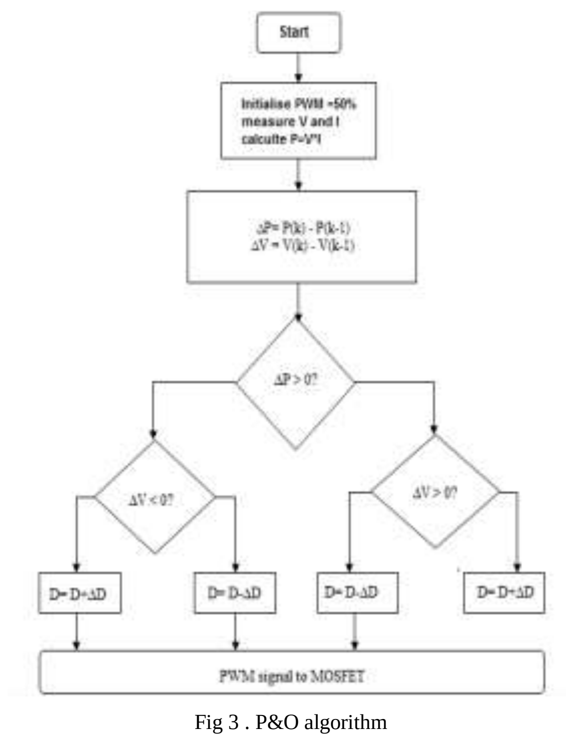

Fig 3 . P&O algorithm

D. Buck converter:

The figure4 shows the buck converter circuit which is responsible for stepping down the solar output voltage to the voltage required by the battery. MOSFET is used as a switch and it is driver by a gate driver circuit. The input to gate driver circuit is coming from the microcontroller in the form of PWM pulses.

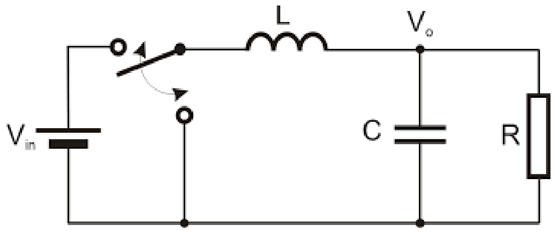

Fig 4 . Buck converter circuit

Buck converter calculation:

We now see the design of buck converter[9] for input voltage of 18v approx.

The output current is given by ratio of maximum power to the output voltage.

$$Output\ Current(Iout) = \frac{Max.Power}{Vout} = \frac{10W}{12V}$$
$$= 0.833A$$

Switching frequency depends on the ripple consideration. The amount ripple to be allowed for inductor current and capacitor voltage, affects the switching frequency. Less the ripple, more is the switching frequency. Frequency of the PWM signal is chosen to be 100kHz. This is obtained from the microcontroller.

$$Switchingf\ requency\ =\ 100kHz$$

Duty cycle of the PWM signal is related to output voltage by,

$$DutyCycle(D)\ = \frac{Vout}{Vin} = \frac{12}{18} = \ 0.6667$$

Ripple current (dI) is generally between 30% to 40% of the load current. Therefore, Ripple current is given by,

$$dI\ =\ 35\%\ of\ rated\ current\ =\ 35\%\ of\ 0.833$$
$$= 0.292$$

Inductor value is calculated using,

$$L\ =\ (V\ in - \&V\ out) * D * \left(\frac{1}{Fsw}\right) * \frac{1}{dI}$$

Where,

D = duty cycle

dI = ripple current

Fsw= switching frequency

$$\therefore L\ = (18 - 12) *\ 0.6667\ * \left(\frac{1}{100 * 10^3}\right)\frac{1}{0.292}$$
$$= 136.99uH$$

$$Inductor\ Peakcurrent\ =\ Iout\ + \frac{dI}{2}$$
$$=\ 0.833\ + \frac{0.292}{2} =\ 0.979A$$

Considering voltage ripple to be 20mV,

$$voltage\ ripple(dV\ ) =\ 20mV.$$

We now calculate Capacitor value using formula,

$$Cout = \frac{dI}{8 * Fsw * dV} = \frac{0.292}{8 * 100 * 10^3 * 20 * 10^3}$$
$$= 18.25uF$$

Current through the fast switching diode is,

$$Diodecurrent(I_D) =\ (1\ - D) *\ I_{LOAD}$$
$$=\ (1 - 0.606) * 700mA\ =\ 0.2758A$$
$$Max.diode\ reverse\ voltage\ =\ 12v$$
$$Power\ Dessipation\ =\ I_D\ *\ V_F\ =\ 0.2758 *\ 0.4$$
$$=\ 0.11W$$

The above calculation gives the component values of buck converter. Figure5 shows the inductor current and Figure6 shows the output voltage of buck converter when simulated using MATLAB Simulink.

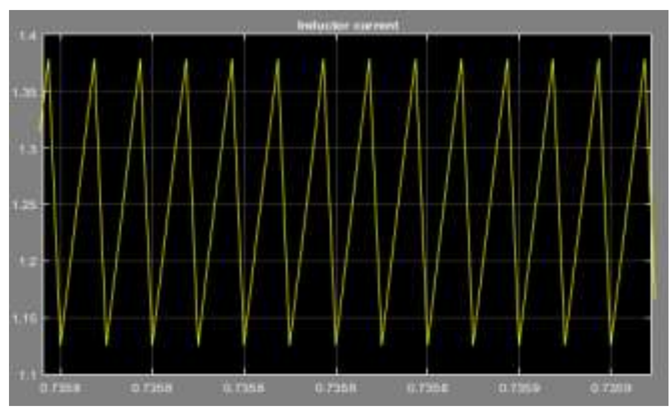

Fig 5 .Inductor current

Figure 6 show that buck converter effectively steps down 18v to 13V approximately.

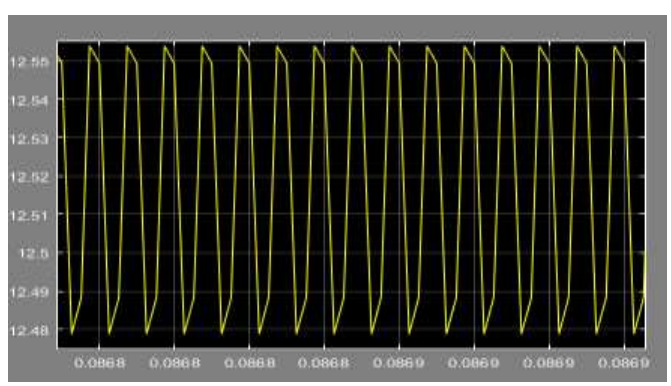

Fig 6 . Output Voltage of buck converter

III. CONCLUSIONS

The load calculation for a single rural house was done with minimum lighting requirements. The cost for installation of off-grid solar system was estimated. Load calculation on hourly basis showed the peak time of power usage. Automating the lights using various algorithms and sensors can further reduce the power consumption and cost. A study on various components of solar system was done. Perturb and Observe was the commonly used algorithm for obtaining MPP.

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