8. Mobile Charging for Off-grid Areas

Risha Mal, Souvik Dey, Saharab Mohsin, Gyandeep Daimari
Electrical Engineering Department, National Institute of Technology Silchar, Assam, India.

ABSTRACT

This paper signifies that communication and access to internet is also for the population residing in remote locations and off-grid areas. The vital necessity is to charge the gadget to access the network. Most predominantly mobiles phones are used for communication. Therefore, it is essential to charge the mobile phones even in off-grid areas. Sustainable solutions like solar and thermoelectric mobile charger will be helpful to uplift access to communication for such regions. The thermoelectric generator is integrated into a cookstove for power generation. The two technologies are broadly discussed with its design and development in this paper mainly to uplift rural areas for access to 5G communication.

Keywords–*thermoelectric generator (TEG); biomass; combustion; Solar; mobile charger.*

INTRODUCTION

The mobile phone has to keep charged to provide instantaneous communication under off-grid conditions. The challenge is to charge the mobiles even where there is no electricity and still people has access to internet communication. The electrification rates in Indian rural areas are daunting. One third of the rural population of India (approximately 8.2 million household) still remains un-electrified [4]. The majority states are, Meghalaya, Arunachal Pradesh, Assam, Nagaland and Uttar Pradesh. Together these states held nearly 80% of the total remaining un-electrified household base. There are other conditions like camping, hiking, some military operations in remote areas where un-interrupted communication is required. Hence, charging of mobile phones become extremely necessary in these conditions. Therefore, two technologies are demonstrated in this paper to provide charging of phones in off-grid areas.

The first technology is a thermoelectric generator integrated biomass cook stove. In rural areas people use to cook food in traditional biomass cook stove. The heat of the burning biomass can be harnessed and a thermoelectric module can be introduced to convert the heat energy into electricity. The electricity generated can be used for charging the battery of a mobile.

The second technology is a solar PV mobile battery charger. The conversion of sunlight into electricity through semiconductor materials exhibit PV effect. This electrical energy can be utilized to store in a battery and later used for charging mobile phones. The major drawbacks of solar PV battery charger is that it require high initial cost, low efficiency and they are weather dependent. Therefore, to maintain maximum power from the PV panel, a maximum power point tracker (MPPT) is developed. The developed PV mobile charger is portable and almost maintenance free. The novelty is the design of a compact battery charger by solar PV whose power can be used for charging mobile phone and lighting LED so that the mobile has not to be kept along the solar panel for charging. Otherwise the intense heat may damage the device.

TECHNOLOGY DEVELOPMENT

A. STOVE TECHNOLOGY

A biomass cookstove is a heating device that helps user to cook food in traditional way mostly in developing countries. The fuel required for cooking in cookstoves are usually organic waste like fire wood, cow dung cakes, crop residues, corn cobs etc. The burning of organic waste results in high harmful emissions in the form of smoke and soot. The emissions are the resultant of incomplete combustion of fuel due to insufficient air-to-fuel ratio. Approximately half of the world's population cooks food on biomass cookstoves. The harmful effects of indoor air pollution are affected to women and children. The gathering of fuel for cooking sometime leads to women drudgery due to travelling longer miles to fetch fuel [1]. The traditional biomass cookstove is generally manufactured by the cook itself with the use of clay, biomass and bricks. The making of these biomass cookstove is the most convenient procedure for rural people due to its simplicity, effectiveness, low or almost no cost of manufacturing and ease of re-building once damaged. The concern of harmful emissions from the biomass cookstove has led to researchers to put efforts on building improved cookstove with less emissions and low fuel consumption. The forced draft biomass cookstove provides better mixing of air with fuel which results in better combustion and low emissions compared to all other types of designs. There are numerous designs of forced draft biomass cookstoves in the market. These forced draft cookstoves run their fan with the help of power supply or rechargeable batteries.

To make an off-grid forced draft cookstove a TEG is used to run the fan. The excess power generated by the TEG is used for charging a battery whose power is later used to charge mobile phones.

B. SOLAR PV TECHNOLOGY

An uninterrupted power supply is required for the charging of mobile phones. Technology and communication are intertwined with each other closely. Communication has become wireless and done with the help of mobile phones. These mobiles are operated with the help of rechargeable batteries. Therefore, it becomes necessary to charge these phones for the access of network. Statistics indicate that about 24 percent population have smart mobile phones in India. According to TRAI (Telecom Regulatory Authority of India) data, tele-density in rural India is growing at a much faster rate than in urban India [3]. The penetration of smart phones will be even more if the charging will be hassle free, portable and uninterrupted. Many rural household do not have smart phones because they are not connected to grid supply to charge their mobiles. To make communication accessible to off-grid population a solar PV mobile charger could be used.

PERFORMANCE CHARACTERISTICS OF TEG

When a semiconductor is heated the charge carrier tend to flow from hot junction to cold junction. The non-uniform distribution of charge carriers help to build charge that results in back e.m.f. and restricts further flow of charge. This phenomenon of conversion of heat energy to develop electrical power is known as Seebeck effect. This effect was first observed by Thomas J. Seebeck in 1821. The junctions of the TEG are made up of dissimilar p-type and n-type materials as shown in figure 8-1. They are connected electrically in series and thermally in parallel [6]. The p-type junctions have more number of holes and n-type junctions have more number of electrons.

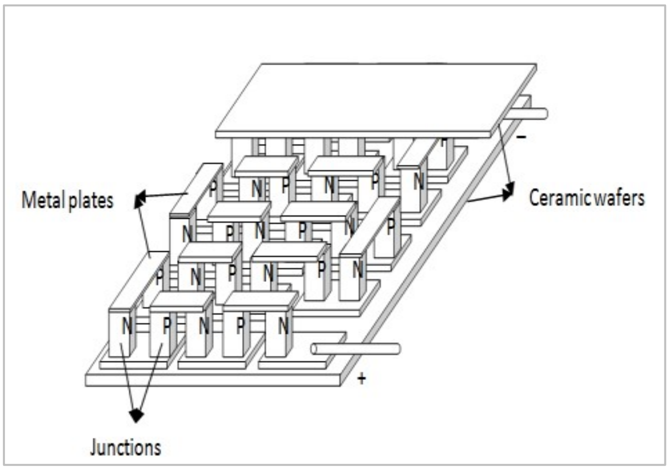


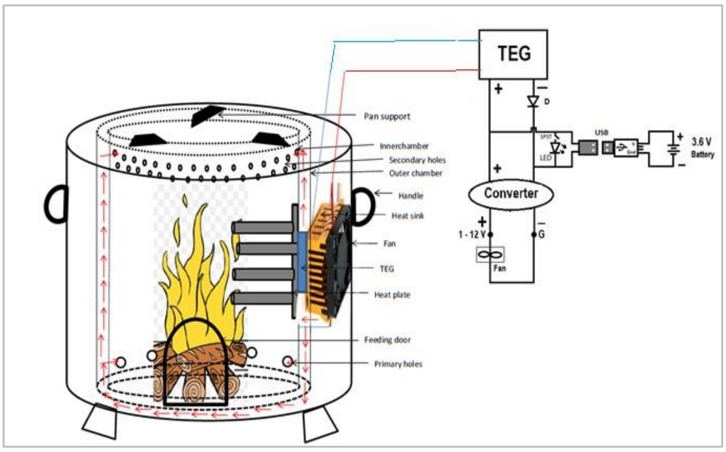
Figure 8-1 Arrangement of junctions in a TEG module

If we consider hot side of the module at temperature T_H and cold side of the module at temperature TC, the charge carriers will flow from T_H to T_C. The arrangement is such that alternate p and n junctions are connected with each other with the help of metal plates to allow flow of current. The resulting voltage that is developed by connecting two dissimilar materials of p-type and n-type whose junctions are a two different temperatures is given by equation 1.

$$V = (\alpha_p - \alpha_n)(T_H - T_C). \quad (1)$$

Where α is the Seebeck coefficient V/°C, T_H is the hot side temperature °C, and T_C is the cold side temperature °C.

The schematic of TEG integrated cookstove is shown in figure 8-2.



Figur 8-2 Schematic of TEG cookstove [8]

The figure 8-2 shows that a stainless plate with probes is inserted inside the combustion chamber. The TEG is sandwiched between the heat plate and the heat sink. The heat plate serves as the hot side of the TEG and the heat sink serves as the cold side of the TEG. The temperature difference between the hot side and the cold side of the TEG is proportional to the output voltage. The rise of voltage is from 0V to a maximum of 5V with a 1.4W load of a DC fan. The DC fan runs at a voltage of 12V. Therefore, it becomes necessary to steup the output voltage of the TEG. A DC-DC boost converter with the capacity to stepup minimum input voltage of 1V to output voltage of 12V is used for the fan. The TEG is capable to generate a power output of 8W. The fan and other electronics take around maximum of 2W. The remaining power is utilized to charge the mobile phone battery. The cookstove has multiple advantages. It provides clean combustion with less harmful emissions and also has the facility to charge the mobile for communication and internet access. The actual power output of the TEG is given by equation 2,

$$P_{actual} = V_{load} \times I_{load} \quad (2)$$

Where, load is the DC-DC step up converter, fan and LED light.

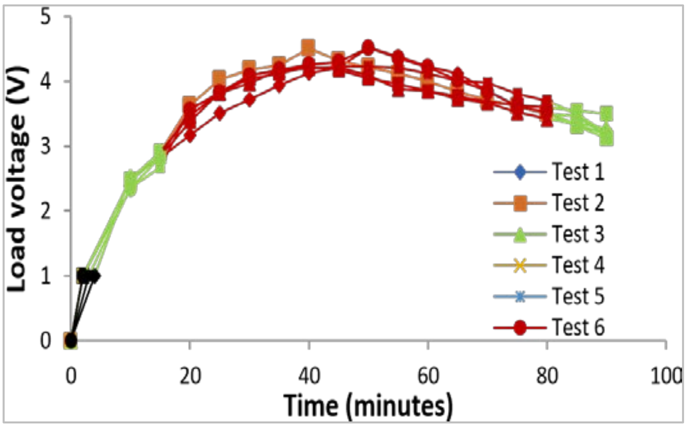


Figure 8-3 omparison of load voltage with respect to time where black marker shows that the voltage is not significant for any application with respect to time, green marker shows the range of running fan only, and red marker shows the running of fan and lighting

The figure 8-3 shows that the fan takes around 2-4 minutes to start after ignition of the biomass inside the cookstove chamber. The fan runs for around 20-25 minutes and thereafter the power output is sufficient to light a 2W LED light. The cookstove is feed with 1kg of biomass for one hour. This enable TEG to power LED light for one hour. In place of LED light a mobile phone battery can also be connected for charging.

From the figure 8-4 it may be observed that the maximum power output of the TEG is nearly 6W. The electronics and the dc-fan consume nearly 3W and thus nearly extra 2-3W power is available for other applications. A LED light of 2W is tried simultaneously with dc-fan for lighting purpose without compromising the speed of the dc-fan.

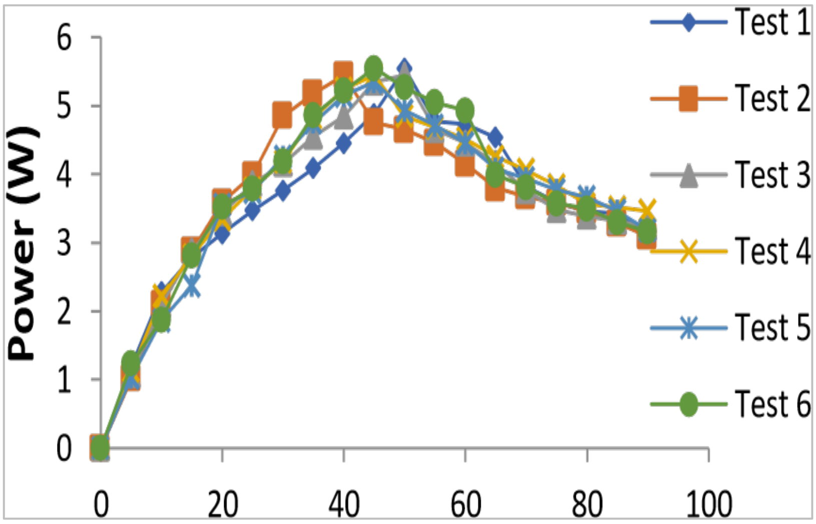


Figure 8-4 Comparison of power output with respect to time.

SIMULATION CHARACTERISTICS OF SOLAR PV

A low power solar battery charger can solve the above problem off-grid mobile charging. But though solar energy is available throughout the day its insolation varies from morning to evening and with changing climatic conditions. As the efficiency of solar PV panel is quiet low it becomes necessary to extract maximum power from the PV panel at any given period of time. Therefore, Perturb and Observe algorithm is used to track the maximum power point. It deals with the designing and implementation of low power PV integrated solar battery charger which can store charge energy and can be used whenever needed. As it is portable it can be carried anywhere easily. High frequency DC-DC Buck converter is used to interface the PV panel with load. A rechargeable lithium ion battery is connected across the terminals of the buck converter for storing the charge. A low power PV panel can also be used for tracing the maximum power and voltage by using maximum power point tracking methods. There are many MPPT methods such as Perturb and Observe, incremental conductance, Fractional short circuit current, Fractional open circuit voltage etc. Out of which Perturb and Observe method is used as it is easier to implement and also the time complexity of the algorithm is very less. Lithium ion batteries are rechargeable and use renewable sources for recharging like solar power. They also tolerate movement and temperature changes, as well as maintain their power delivery during use. A combination of both low voltage PV panel and lithium ion battery can be used for solving various power shortage problems.

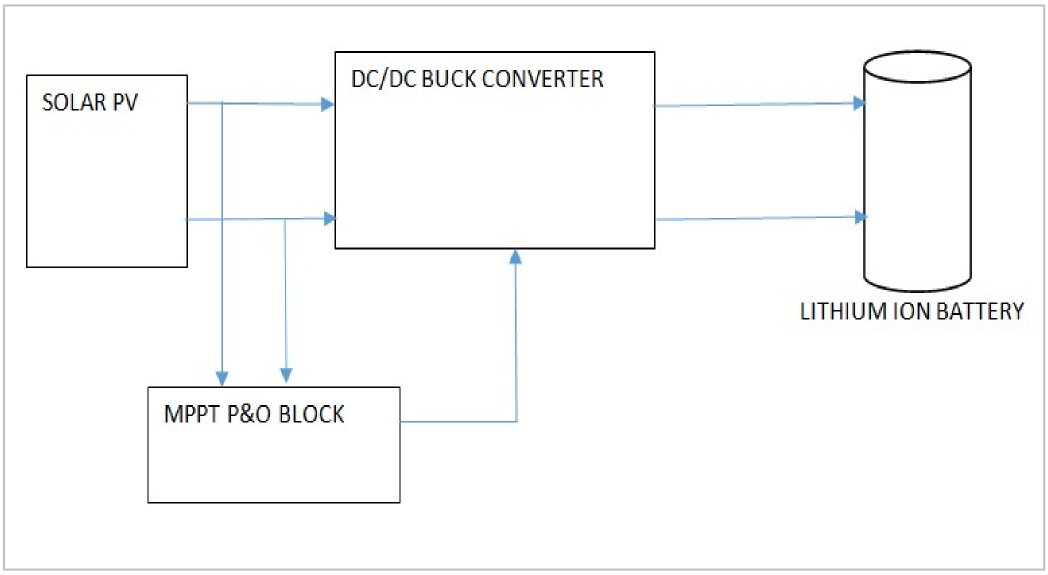


Figure 8-5 Block diagram of solar PV mobile charger

As the working model to be developed has to be of cost efficient as well as less bulky, the ratings and specifications of the PV panel and battery chosen are as shown table 8-1.

Table 8-1 Ratings and specifications of the PV panel and battery

SNo.	Components	Ratings and Specifications
1	PV panel	V_{oc}=15V , I_{sc}=1.3A, P_{max}=16.2W V_{max}=13.5V, Imax=1.2A
2	Lithium Battery	Nominal Voltage=4.2V, Rated Capacity= 5Ah

A buck converter is used to step down the voltage obtained from the PV to a voltage suitable for charging the battery. Since the load used here is lithium battery which is a nonlinear load, so for the designing of buck converter hit and trial approach is used. Considering maximum value of duty cycle as

$$D_{max} = V_{out}/V_{in} = 6/13.5 = 0.45 \quad (3)$$

As MPPT algorithm P&O is used to track the maximum power point, the duty cycle will vary accordingly [9]. Below are the results shown with various values of inductor L and capacitor C.

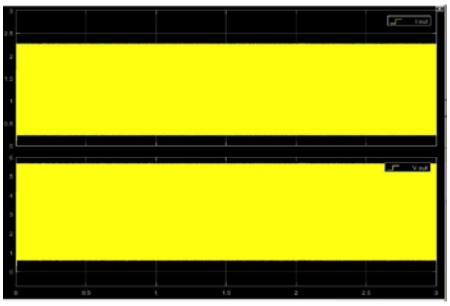


Figure 8-6 Output voltage and current characteristics for L=0.10 mH , C=0.1μF

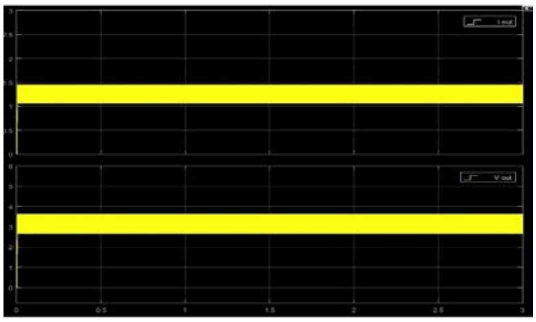


Figure 8-7 Output voltage and current characteristics L=1mH, C= 0.1μF

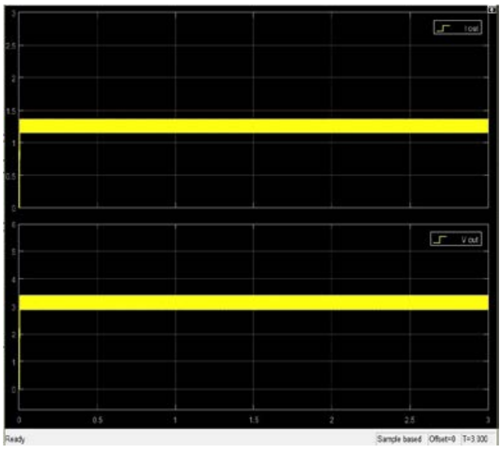


Figure 8-8 Output voltage and current characteristics L=1Mh, C= 1uF

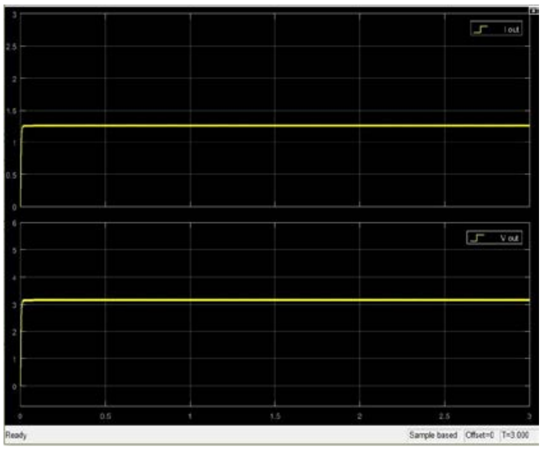


Figure 8-9 Output voltage and current characteristics L=15mH, C= 10uF

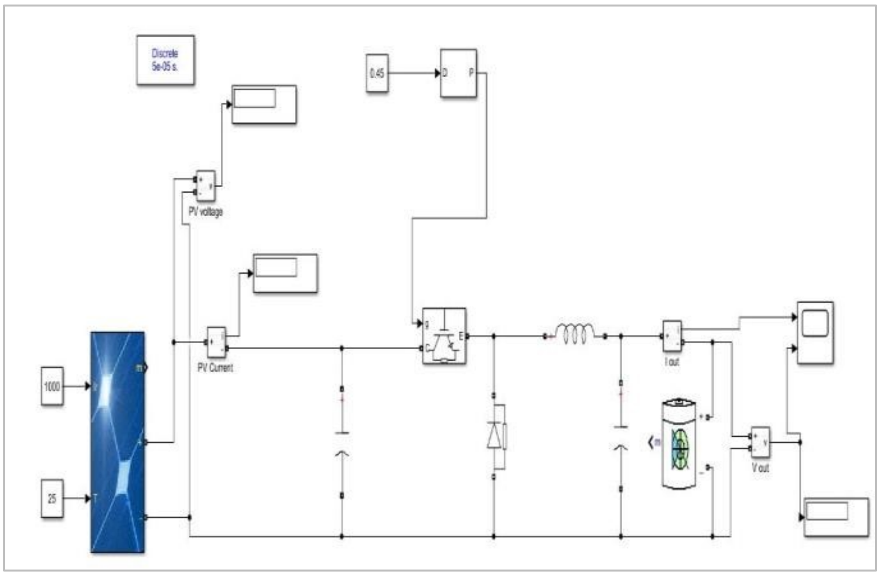


Figure 8-10 Buck converter design

As here it is observed that there is huge amount of ripples, so to reduce it the values of L and C has to be increased. First keeping the value of C same, L is increased. Similarly, with this approach L and C values are further increased for getting minimal ripples possible.

The design of converter is shown in figure 8-10

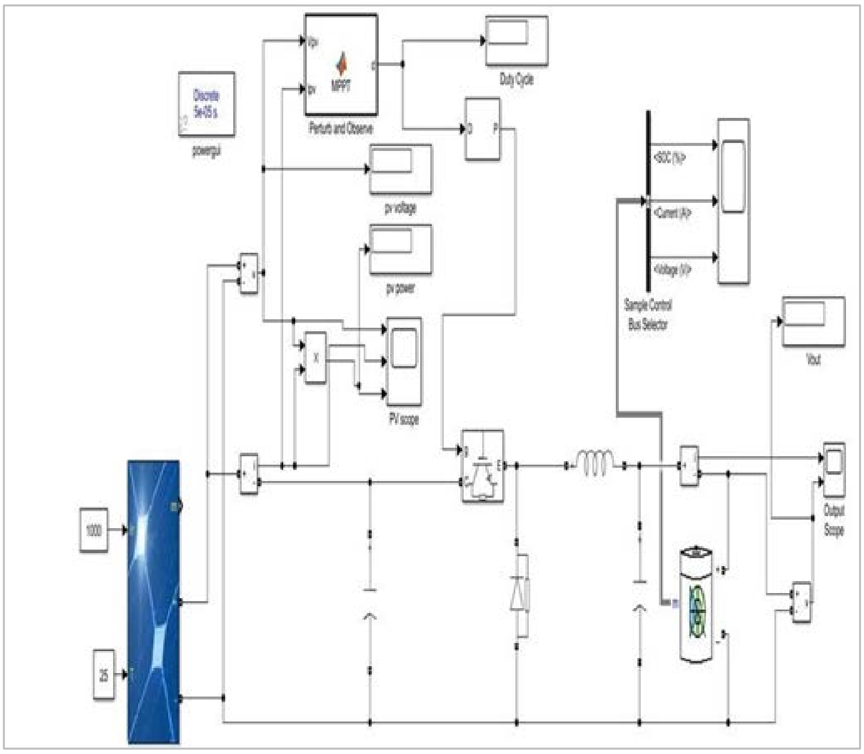


Figure 8-11 Design prototype of solar PV mobile charger

The testing the MPPT code simulation is done and the results are matched with the reference values.

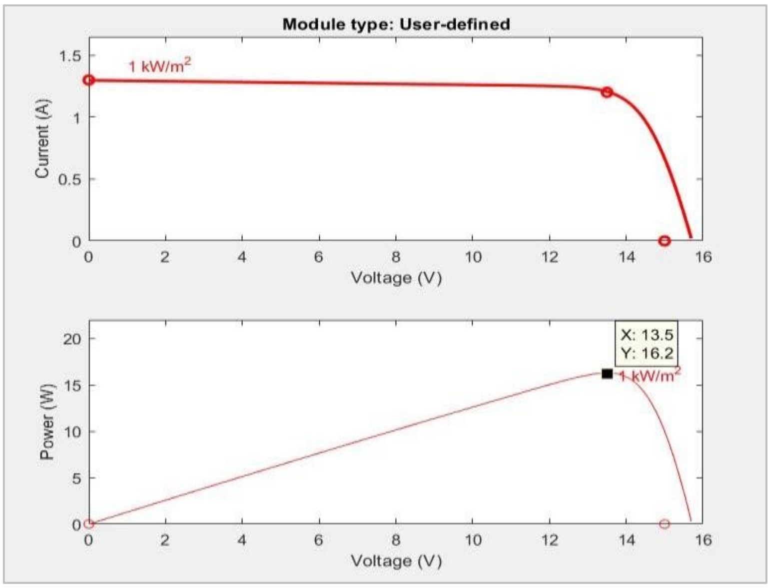


Figure 8-12 Value of power after simulation

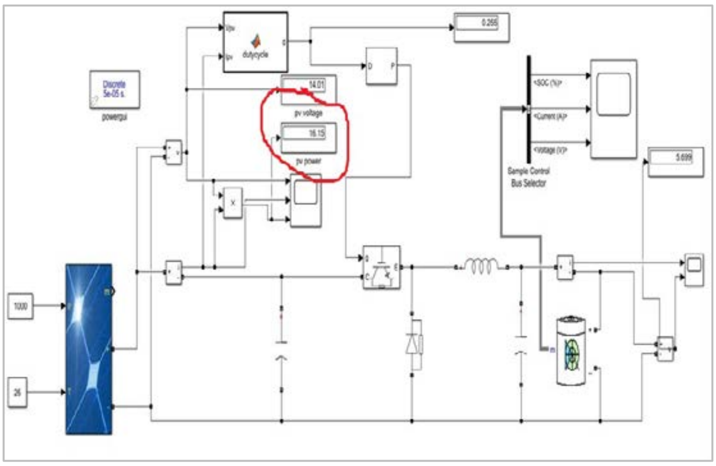


Figure 8-13 Reference values of maximum voltage and power as generated

From figure 8-13, it is observed that the value of maximum power after simulation is nearly equal to the reference as generated from the PV panel. So it successfully tracks the maximum power from the PV panel using MATLAB.

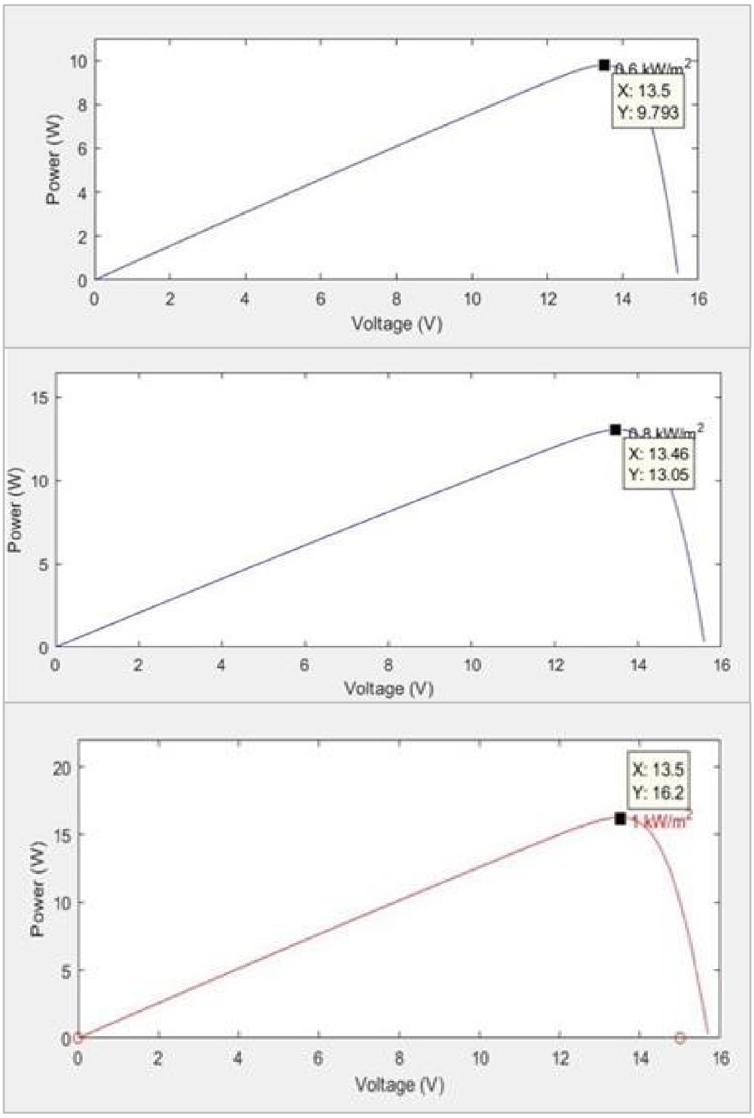


Figure 8-14 Reference power versus voltage generated from PV for different

As the maximum value of voltage is maintained constant for different values of irradiations, it can be concluded that the MPPT code is successful in tracing the maximum power point. Final values of parameters for designing the buck converter is shown in table 8-2.

Table 8-2 Parameters for designing the buck converter

Sl. No.	Components	Rating
1	PV panel	Voc=15V, I_{SC}=1.3A,P=16.2W
2	Inductor for buck converter	15mH
3	Capacitor for buck converter	10µF
4	DC link for buck converter	300µF
5	Switching frequency of PWM	5000 Hz

Now for testing whether the battery is charging, the initial State of Charge (SOC) is kept at 2% and simulation is performed. The observed charging characteristics of the battery are as shown below:

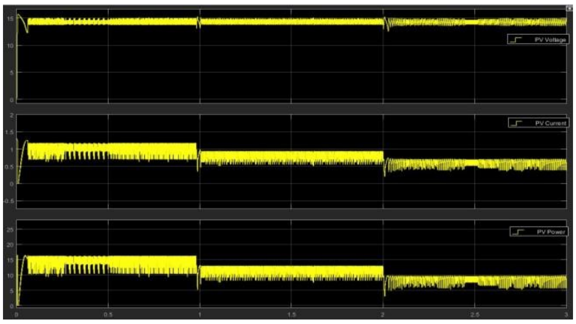


Figure 8-15 Simulation results for different irradiations (1, 0.8, 0.6 KW/M^2)

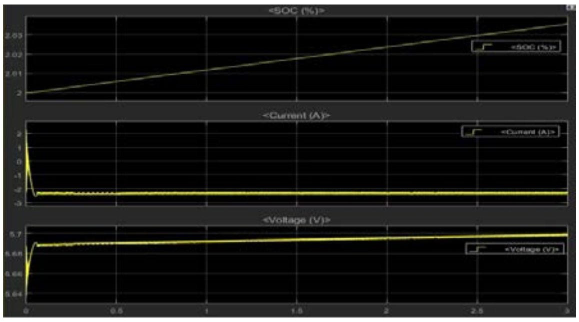


Figure 8-16 . Output waveforms showing SOC (state of charge), battery current and voltage respectively (for 1000 kw/m^2S)

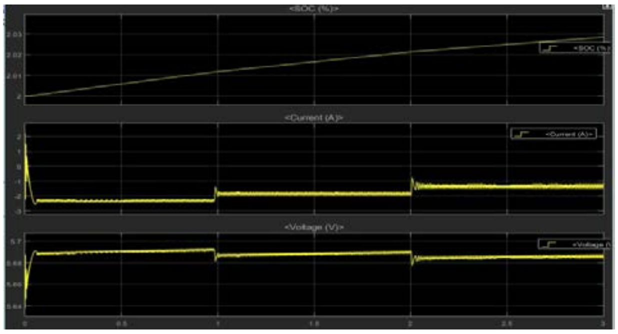


Figure 8-17 Output waveforms showing soc(state of charge),battery current and voltage respectively for changing irradiation

The charge is increasing as can be seen from the waveforms and it can be concluded that the battery is charging. Hence the proposed model is working successfully.

The method presented here use Perturb and Observe method for tracing the maximum power point according to solar irradiance and match load impedance with source impedance to provide maximum power. The MPPT model is more suitable because of less cost, easier circuit design and also better efficiency. Here a rechargeable Lithium ion Battery is used to store the charge and its charging characteristics is shown. As the simulation is successful, its hardware implementation can be done.

COST ANALYSIS

The effective cost of the two technologies has to be estimated as it will be disseminated in rural off-grid areas. Thermoelectric generators available in Indian market do not provide sufficient output. The TEG is imported from Marlow industries, USA. Hence, the cost of the TEG is a bottleneck to make the technology affordable. But, when TEG integrated cookstove is manufactured in bulk the cost reduces effectively.

Table 8-3 Effective cost of TEG integrated cokstove

Parts	TG1208-1LS(INR)
TEG+ ceramic wafer + grease	2665
Hot plate	520
Heat Sink	520
Electronics	200
Batteries	150
Stove	1000
Miscellaneous	200
Total	**5255**

Table 8-4 Effective cost of solar based mobile charger

S.No.	Component	Rating	Price (Rs)
1	PV panel	16W	700
2	arduino	--	350
3	Lithium ion battery	3.6V	100
4	capacitor	10uF	35
		300uF	100
5	inductor	15mH	40
6	IGBT	313W	120
	Total		**1445**

The scaling up of both the technologies will help to reduce the cost of the products. Therefore, on successful implementation of the two technologies, bulk manufacturing is appreciated to make the products affordable and accessible to rural households.

CONCLUSION

Internet has become affordable to most of the population in India. But, a great deal of people residing in rural areas is derived from internet because of being off-grid. Mobile charging in off-grid areas is a challenge. Therefore, the TEG integrated cookstove will have positive impact on health as well as charge mobile phone and the solar PV mobile charger is cheaper, portable and will help charging mobile in off-grid areas. Hence, not having a power supply will not pose as a barrier to access internet even in remote rural areas. The TEG integrated cookstove has been developed and running successfully in some parts of India. The cookstove efficiently cuts down harmful emissions resulting from biomass burning and improves thermal efficiency of the cookstove. It is also capable of mobile charging and lighting a LED lamp. The low watt Solar PV mobile charger has been simulated in MATLAB and successfully executed. In future the PV integrated solar mobile charger has to be developed as a product with efficient design and test the results for validation in field.

ACKNOWLEDGEMENT

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