Solar Photovoltaic Powered Sailing Boat Using Buck Converter

Soumya Das*, Pradip Kumar Sadhu, Nitai Pal**, Gourav Majumdar***, Saswata Mukherjee******
* Departement of Electrical Engineering, UIT, Burdwan University, Burdwan-713104, India
** Electrical Engineering Department, Indian School of Mines (under MHRD, Govt. of India), Dhanbad - 826004, India
*** Departement of Electrical Engineering, KIIT University, Bhubaneswar 751024, Odisha, India
**** Departement of Electrical Engineering, WBUT, West Bengal -700064, India

Article Info

Article history:

Received Sep 20, 2014
Revised Jan 13, 2015
Accepted Jan 25, 2015

Keyword:

Buck Converter
Ideal Switch
Matlab Simulink
PV
Solar Sailing Boat

ABSTRACT

The main objective of this paper is to establish technical and economical aspects of the application of stand-alone photovoltaic (PV) system in sailing boat using a buck converter in order to enhance the power generation and also to minimize the cost. Performance and control of dc-dc converter, suitable for photovoltaic (PV) applications, is presented here. A buck converter is employed here which extracts complete power from the PV source and feeds into the dc load. The power, which is fed into the load, is sufficient to drive a boat. With the help of matlab simulink software PV module and buck model has been designed and simulated and also compared with theoretical predictions.

Corresponding Author:

Soumya Das,
Departement of Electrical Engineering,
University Institute of Technology, Burdwan University,
Burdwan, West Bengal-713104, India.
Email: Soumya.sd1984@gmail.com

1. INTRODUCTION

Transport in Water ways is definitely one of the most indispensable life sustenance features of the modern society; practically all this energy comes from fossil fuels, it creates heavy ecological problems in all large cities. The main solution of these problems lies in the proper use of the renewable energy sources, and there are many plausible examples of this kind, like solar powered sailing boat which uses only solar energy converted by Photo Voltaic Converters (PVCs) and feeding a dc load [1]. It is important to generate the pollution-free, Eco friendly natural energy. Electricity generated from photovoltaic (PV) power systems is a major renewable energy source which involves almost zero greenhouse gas emission and doesn't consume any fossil fuel [2]-[4]. Photovoltaic energy is an efficient source of energy: it is renewable, inexhaustible and pollution free, for that, it is more and more rapidly been used as an energy source. In standalone photovoltaic generator (PVG), the generated energy is used either directly or associated with a storage in battery or in an energy reserve, e.g. hydraulic. In connected PVG, it may be associated with inverters and voltage step-up or step-down systems (i.e. choppers). A PVG with good efficiency can be carried out if it constantly converts maximum available solar power all the time even in case of rainy day [5]. Here this converter is essentially buck converters feeding a dc load. Here, the buck converter extracts complete power from the PV source and feeds into the load [6], [7].

2. THE PROPOSED METHOD

2.1. Photo Volataic System

Recent research has dealt with most of the DC/DC converters in order to find the most compatible type in terms of overall power system efficiency. The block diagram of the PV system is shown in Figure 1. This consists of a photovoltaic generator (PVG), a buck dc–dc converter and a dc load. The role of the power converter is to interface the PV array output to the dc load [8].

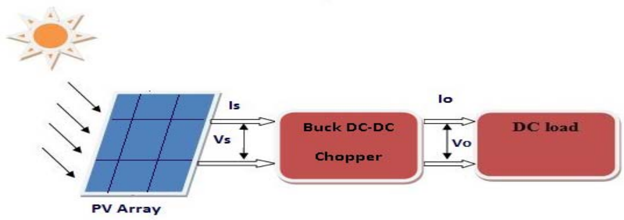

Figure 1. Block diagram of solar PV system

2.2. Photo Volataic Powered Sailing Boat

Schematic diagram of proposed photovoltaic powered sailing boat with buck converter is shown in Figure 2. Solar energy conversion into electrical power is naturally performed by solar cells [9]. The PV generator transfers the descendent solar radiation to a direct voltage and current. These ends provide a boost chopper. The load of chopper is the separately exited motor [10].

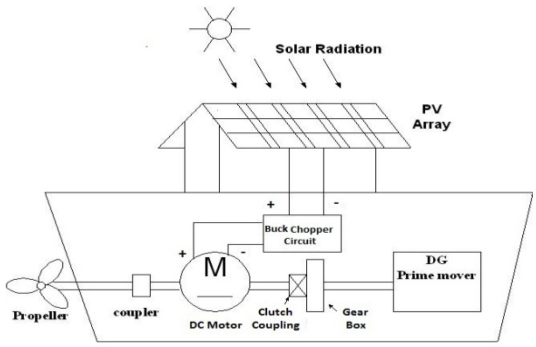

Figure 2. Schematic Diagram of PV powered Sailing Boat

Solar panels are rarely connected to the electrical equipment. directly, except grid connected system. Power generated from the solar panel depends on the strength of the sun light. Boost converter is providing the necessary supply on the sunny day as well as cloudy day. Output of the motor also connected to a propeller through a coupler. On the other hand another side of the motor shaft is connected with a diesel generator (DG) prime mover through another clutch coupler. When solar PV does not generate necessary power then pressing the coupler this DG prime mover is connected with the motor shaft. More over this DG generator is connected as a backup protection. Cost competitive cover design with fluorides in place of glass is to be good alternatives when considering cost and weight reduction of PV modules [11]. If the entire weight of a boat is lower, the energy is desired reasonably less [12].

3. RESEARCH METHOD

3.1. DC to DC Buck Converter

The step-down dc-dc converter, commonly known as a buck converter, is shown in figure below. The buck converter is characterized by buck converter with LC filter block and load block. A single stage LC filter will be used so only one inductor and one capacitor exist in the circuit [13]. Typical waveforms in the converter are shown in below figure under the assumption that the inductor current is always positive. The state of the converter in which the inductor current is never zero for any period of time is called the continuous conduction mode (CCM). It can be seen from the circuit that when the switch S is commanded to the on state, the diode D is reverse-biased. When the switch is off, the diode conducts to support an uninterrupted current in the inductor. It has been studied that the efficiency of the DC to DC converter is maximum for a buck converter. In this case buck converter has been used for PV powered sailing boat system which requires 110 V at the output end.

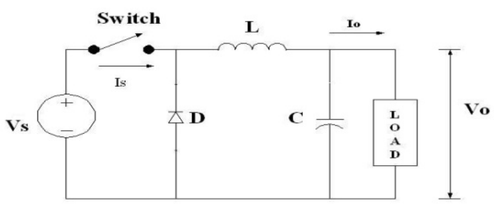

Figure 3. Circuit Diagram of Buck Converter

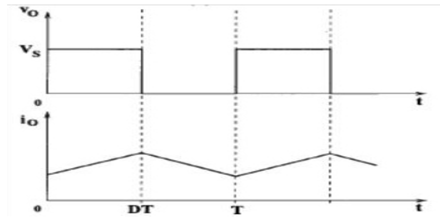

Figure 4. Waveform of Buck Converter

The voltage across the inductor L is,in general [14],

$$e_L = L\frac{di}{dt} \quad (1)$$

Assuming that the inductor current rises linearly from I_1 to I_2 in time t_1,

$$V_s - V_o = L\frac{I_2-I_1}{t_1} = L\frac{\Delta I}{t_1} \quad (2)$$

$$t_1 = \frac{\Delta IL}{V_s-V_o} \quad (3)$$

And the inductor current fallss linearly from I_2 to I_1 in time t_2,

$$-V_o = -L\frac{\Delta I}{t_2} \quad (4)$$

$$t_2 = L\frac{\Delta I}{V_o} \quad (5)$$

Where $\Delta I = I_2 - I_1$ is the peak to peak ripple current of the inductor L.

$$\Delta I = \frac{(V_s-V_o)t_1}{L} = \frac{V_o t_2}{L} \quad (6)$$

Substituting $t_1 = DT$ and $t_2 = (1-D)T$ yields the average output as:

$$V_o = V_s\frac{t_1}{T} = DV_s \quad (7)$$

The switching period T can be expressed as:

$$T = \frac{1}{f} = t_1 + t_2 = \frac{\Delta IL}{(V_s-V_o)} + \frac{\Delta IL}{V_o} = \frac{\Delta ILV_s}{V_o(V_s-V_o)} \quad (8)$$

This gives the peak to peak ripple current as:

$$\Delta I = \frac{V_o(V_s-V_o)}{fLV_s} \quad (9)$$

$$\Delta I = \frac{V_sD(1-D)}{fL} \quad (10)$$

And the the peak to peak ripple voltage of the capacitor is:

$$\Delta V_c = \frac{V_sD(1-D)}{8LCf^2} \quad (11)$$

3.2. Calculation and Specification for Designing Required PV and Converter Model

Usually it has been seen that a single 1.5 HP dc motor is sufficient for carrying 4 passengers weighing approximately 350 kg in a PV powered sailing boat and if the converter efficiency is considered as 95% then,

I/P to the chopper = (1.5×746)/0.95= 1178 Watt (Aprox)
I/P to the chopper= o/p of PV panel
If single panel is of 300 watt.
No of panel= (1.5×746)/ (0.85×300) =3.9≈4.

3.2.1. Modeling of PV Array Using Matlab

Here in the Matlab simulation of a PV module the parameters of the solar cells are being taken as 300-watt Module. The value of Voc for the module is 44.72volt. As 72 solar cells are being connected in series so individual for a solar cell it is coming 44.72/72=0.62volt. Six solar cells are connceted in series first,then they are masked into a subsystem & three in a series are being added to make it 18 and then two subsystems of 18 are connected in series to make 36. Then two subsystems of 36 are being connected to make it a module of 72 solar cells and finally 4 PV modules are coneected in series[15-21].

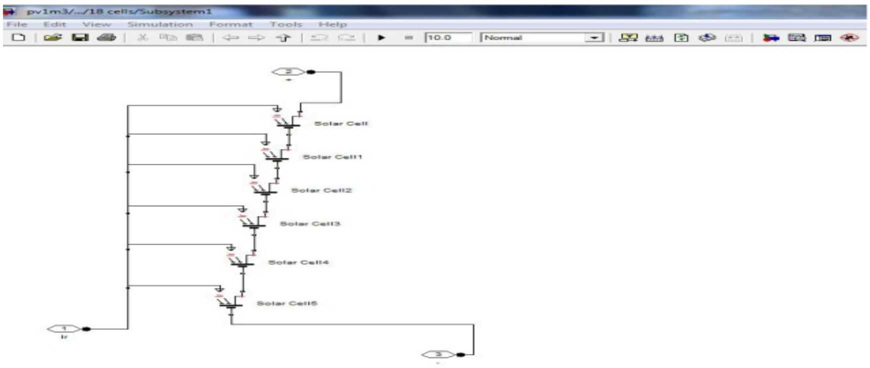

Figure 5. Modelling of Six solar cells are connceted in series

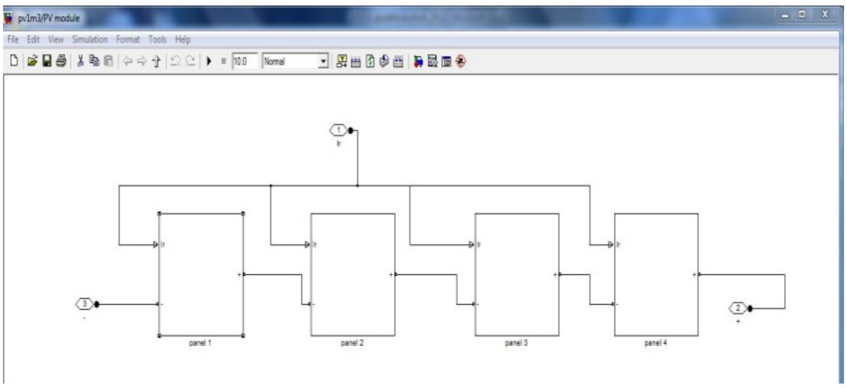

Figure 6. Four PV panels are connected in series

There after it has to be seen whether the model is working properly or not. It is also to be seen if the V_{oc} is coming correct or not & I_{sc} is coming correct or not. It is respectively done by making the load resistance, which is connected to the output of the module, very high (in order of 15.56×10^{6} Ω) to get the value of V_{oc} & again reducing it to a very nominal value of 15.56×10^{-6} Ω to get the short circuit current. The solar insolation is taken as 1000w/m^2. For getting maximum power voltage and maximum power current the value of load resistance should be (V_m / I_m) 17.53Ω.

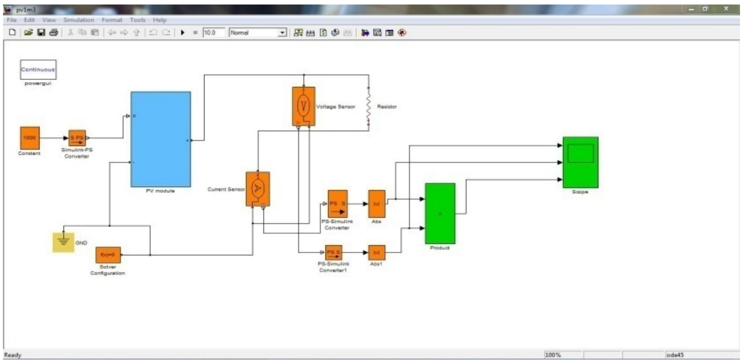

Figure 7. Flow chart algorithm of PV module under Matlab simulink

Table 1. Specification of Single PV module

No. of cells per Module	Maximum Power (watt)	Open Circuit Voltage (Voc) Volt	Short Circuit Current (Isc) Amp	Maximum Power Voltage (V)	Maximum Power Current (A)	Weight (Kg) (Aprox)	Dimensions (Length × Width × Depth) (Aprox)
72	300	44.72	8.62	35.86	8.18	23	77mm × 39mm× 1.5mm

3.2.2. Modeling of Buck Converter

After that the module is connected with a buck converter to make the Voc value step down upto 110volt.In doing that the parameters of buck converter is taken as follows:

Fs=100khz, $\frac{\Delta I}{I0} = 30\%$(According to IEC harmonics should be bounded within 30%.),

$\frac{\Delta Vc}{Vo} = 5\%$ (According to IEC harmonics should be bounded within 5%),

I/P voltage is taken as, V_{in}=35.86×4=143.4volt ≈144 volt (aprox), O/p voltage is taken as, V_o=110volt.

O/p load current is taken as.I_o=8.25A (aprox).

So from the above data duty cycle is to be calculated as, D=76.68%, current ripple ΔI_L= 3.24 amp, Inductor value, L=8.016×10^{-5} H, Capacitor value, C=0.73 uF.

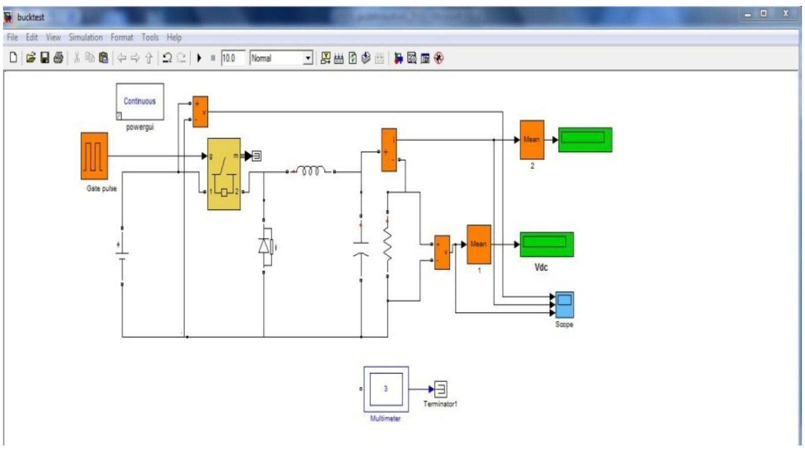

Figure 8. Flow chart algorithm of Buck converter under Matlab simulink

3.2.3. Modeling of PV With Buck Converter

Modeling of PV array and buck converter is already discussed earlier. From the above discussion it has been seen that input of the chopper is the output of PV panel. Now the pv model and the buck converter is being implemented in the same circuit where output from the PV array is fed to the input of buck converter using matlab simulink.

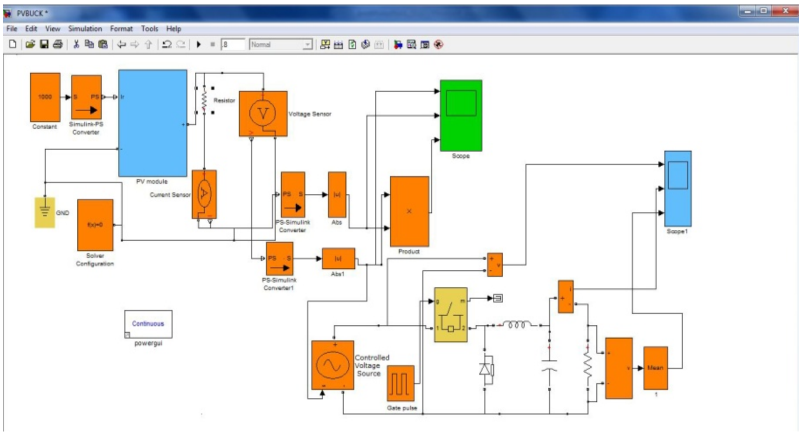

Figure 9. Flow chart algorithm of PV with Buck converter under Matlab simulink

4. RESULTS AND DISCUSSION

As discussed earlier 4 PV modules are connected in series to generate 1178 Watt. Now it has been shown in Table 2 that each PV module can generate maximum power voltage and current are of 35.86 Volt and 8.18 Amp respectively. So the maximum power output voltage of the PV array is 143.44 Volt. But according to the simulation graph the voltage is approximately 144.30 Volt and current is 8.2 approximately. All the experimental values are nearly same as with the theoretical ones. The slight difference in the values is not hampering the proposed model.

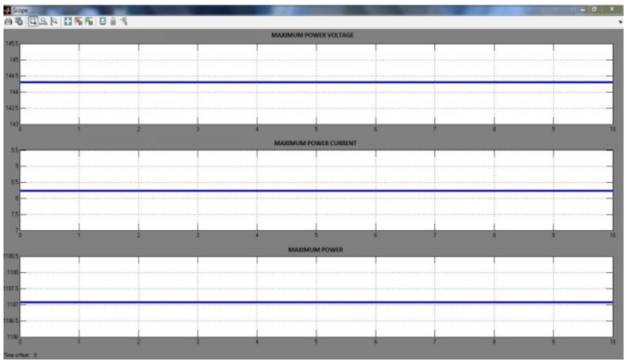

Figure 10. Simulation result of maximum voltage, current and power in PV array

Similarly, from the above calculation output voltage for the buck converter is 110 Volt. But form the simulation result the output voltage is 113.10 Volt and output current is 11.10 Amp.

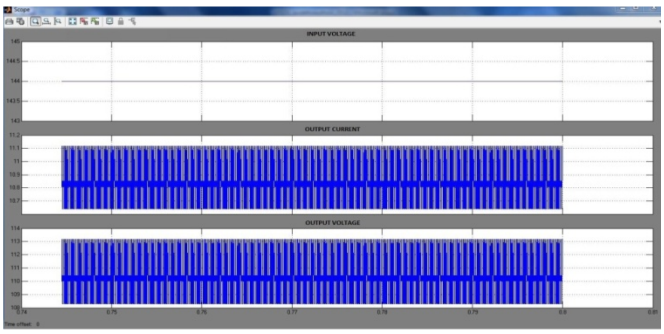

Figure 11. Simulation result of Buck converter

Likewise, after combining both the PV and converter circuit in Matlab simulink the Output voltage of PV array 144.30 Volt which is also the input voltage of buck converter. Now the output of the buck converter is 110.44 Volt.

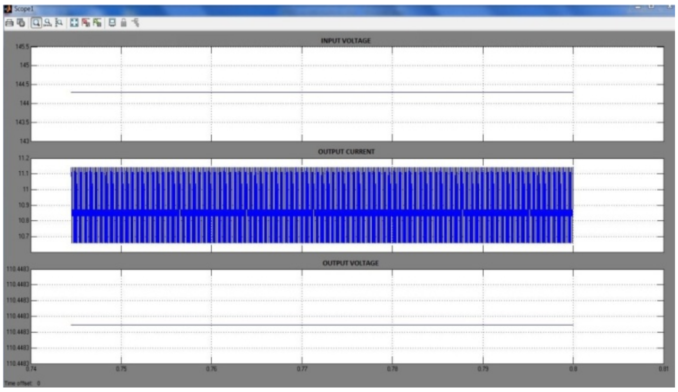

Figure 12. Simulation result of PV with Buck

5. CONCLUSION

Solar PV powered sailing boat using buck converter is proposed here. The effectiveness of the proposed control scheme is tested. This is a new and innovative application which is fully environmental friendly and is almost polution less. As the upper portion of the boat is unused, solar panels are implemented in that portion quite easily, no extra space is required. Fuel cost is not required in day time due to the presence of sunlight. lastly, energy pay back period will be lesser than diesel run boat.

REFERENCES

[1] P Vorobiev, Yu. Vorobiev. *Automatic Sun Tracking Solar Electric Systems for Applications on Transport*. 7th International Conference on Electrical Engineering, Computing Science and Automatic Control. 2010.
[2] Nobuyulu Kasa, Takahiko Iida, Hideo Iwamoto. An inverter using buck-boost type chopper circuits for popular small-scale photovoltaic power system. *IEEE.* 1999.
[3] Peng Zhang, Wenyuan Li, Sherwin Li, Yang Wang, Weidong Xiao. Reliability assessment of photovoltaic power systems: Review of current status and future perspectives. *Applied Energy.* 2013; 104(2013): 822–833,
[4] M Nagao, H Horikawa, K Harada. Photovoltaic System using Buck-Boost PWM Inverter. *Trans. of IEEJ.* 1994; ll4(D): 885-892.
[5] A Zegaoui, M Aillerie, P Petit, JP Sawicki, JP Charles, AW Belarbi. Dynamic behaviour of PV generator trackers under irradiation and temperature changes. *Solar Energy*. 2011; 85(2011): 2953–2964.
[6] Veerachary Mummadi. *Multi-Input Integrated Buck-Boost Converter For Photovoltaic Applications*. IEEE Conference. 2008.
[7] Yaow Ming Chen, Yuan Chuan Liu, Sheng Hsien Lin. Double-input PWM dc/dc converter for high/low voltage sources. *IEEE Trans on Ind. Electronics.* 2006; 53(5): 1538-1545.
[8] R Anusuyadevi, P Suresh Pandiarajan, J Muruga Bharathi. Sliding Mode Controller based Maximum Power PointTracking of DC to DC Boost Converter. *IJPEDS.* 2013; 3: 321-327.
[9] H El Fadil, F Giri. Climatic sensor less maximum power point tracking in PV generation systems. *Science Direct*. 2011; 19(2011): 513–521.
[10] A Saadi, A Moussi. *Optimisation of Chopping ratio of Back-Boost Converter by MPPT technique with a variable reference voltage applied to the Photovoltaic Water Pumping System.* IEEE conference Canada. 2006.
[11] T Gorter, AHME Reinders. A comparison of 15 polymers for application in photovoltaic modules in PV-powered boats. *Applied Energy*. 2012; 92(2012): 286–297.
[12] Gorter T, Voerman E, Joore P, Reinders A, Van Houten F. *PV-boats: design issues in the realization of PV-powered boats*. 25th European Photovoltaic Solar Energy Conference/5th World Conference on Photovoltaic Energy Conversion. Valencia, Spain. 2010.
[13] F Yusivar, MY Farabi, R Suryadiningrat, WW Ananduta, Y Syaifudin. Buck-Converter Photovoltaic Simulator. *IJPEDS*. 2011; 1: 156-167.
[14] Power Electronics Handbook by M.H.Rashid.
[15] Mr G Venkateswarlu, Dr P Sangameswar Raju. SIMSCAPE MODEL OF PHOTOVOLTAIC CELL. *IJAREEIE*. 2013; 2(5): 1766-1772.
[16] A Rostami, K Abbasian, N Gorji. EfficiencyOptimization in a Rainbow Quantum Dot Solar Cell. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*. 2011; 3(7): 106-109.

[17] M Sojoudi, R Madatov, T Sojoudi. Optimization of Efficiency of Solar Cells by Accelerated Electron ray to Have an Optimal and Constant Energy. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*. 2011; 3(9): 68-71.
[18] Yuncong Jiang, Jaber A Abu Qahouq,Mohamed Orabi. *Matlab/Pspice Hybrid Simulation Modeling of Solar PV Cell/Module.* Proceedings of Twenty-Sixth Annual IEEE Applied Power Electronics Conference and Exposition (APEC 2011). 2011; 1244-1250.
[19] RK Nema, Savita Nema, Gayatri Agnihotri. Computer Simulation Based Study of Photovoltaic Cells/Modules and their Experimental Verification. *International Journal of Recent Trends in Engineering*. 2009; 1: 151-156.
[20] Sheriff MA, Babagana B, Maina BT. A Study of Silicon Solar Cells and Modules using PSPICE. *World Journal of Applied Science and Technology.* 2011; 3: 124-130.
[21] Yuncong Jiang, Jaber A Abu Qahouq, I Batarseh. Improved Solar PV Cell Matlab Simulation Model and Comparison. *IEEE International Symposium on Circuits and Systems (ISCAS)*. 2010; 2770-2773.

BIOGRAPHIES OF AUTHORS

Soumya Das received his Bachelor degree in 2007 from WBUT; He received his Post-Graduate degree in 2010 from Jadavpur University, West Bengal, India. Currently, he is working as an Assistant Professor in Electrical Engineering Department of University Institute of Technology, Burdwan University, India. He has total experience of 5 years in teaching. He is presently pursuing Ph.D. programme at the Department of Electrical Engineering, Indian School of Mines, Dhanbad-826004, India. He has guided a large no. of B.Tech and M. Tech students. His current areas of interest are solar photovoltaic system, power electronics applications, computer aided power system analysis, High Voltage Engineering.

Pradip Kumar Sadhu received his Bachelor, Post-Graduate and Ph.D. (Engineering) degrees in 1997, 1999 and 2002 respectively in Electrical Engg. from Jadavpur University, West Bengal, India. Currently, he is working as a Professor in Electrical Engineering Department of Indian School of Mines, Dhanbad, India. He has total experience of 18 years in teaching and industry. He has four Patents. He has several journal and conference publications in national and international level. He is principal investigator of few Govt. funded projects. He has guided a large no. of doctoral candidates and M. Tech students. His current areas of interest are power electronics applications, application of high frequency converter, energy efficient devices, energy efficient drives, computer aided power system analysis, condition monitoring, lighting and communication systems for underground coal mines.

Nitai Pal received his B.Tech. and M.Tech. degrees in Electrical Engineering from University of Calcutta, West Bengal, India. He received his Ph.D. (Engineering) from Jadavpur University, West Bengal, India. He has total experience of twelve years in teaching. He is currently working as an Assistant Professor in the Department of Electrical Engineering, Indian School of Mines, Dhanbad, Jharkhand, India. He has several publications in Journals, International & National conferences. He is the co-investigator of Govt funded project. His current areas of interest are Power electronics application, application of high frequency converters, energy efficient devices, energy efficient drives, lighting and communication systems for underground coal mines.

Gourav Majumder received his Bachelor degree in 2012 from WBUT, West Bengal, India. He received his Post-Graduate degree (Specialization in Power & Energy System) in 2014 from KIIT university Odisha.

Saswata Mukherjee was born in 1993. He received his Bachelor degree in electrical engineering in 2014 from WBUT, West Bengal, India.