An Efficient Solar Pumping System for Rural Areas of Bangladesh

Md. Habib Ullah, Tanvir Ahmad, Md. Niaz Morshedul Haque, Md. Jakaria Rahimi, Ripan Kumar Dhar

Abstract— This research deals with the design and simulation of a simple but efficient photovoltaic water pumping system for rural areas of Bangladesh. The main objectives were to get a cost effective and efficient system employing MPPT. To keep the cost minimized some design consideration are presented. Presently used Buck converter based MPPT is compared with more efficient Buck boost and Cuk converter topologies. The simulations perform comparative tests using actual irradiance data for Bangladesh. The results showed a very compact and efficient result can be obtained the proposed topology including Cuk converter based MPPT.

Index Terms— DC-DC converters, MPPT, PV modules, Solar pumping, Simulation modeling.

1 Introduction

In a country like Bangladesh where farming is one of the strongest pillars of the economics, irrigation system should be very well-equipped and should be managed well. In doing so, we have to ensure adequate supply of electrical power for water pumping as per requirement. In general, AC powered system is economic and takes minimum maintenance when AC power is available from the nearby power grid. However, Due to severe crisis of electricity in Bangladesh at present we have to find some efficient way to resolve this problem. Windmills have been installed traditionally in many rural areas of different places in the world, where water sources are spread over many miles of land and power lines are scarce: many of them are however, inoperative now due to lack of proper maintenance and age. Today, many stand-alone type water pumping systems use internal combustion engines. These systems are portable and easy to install. However, they have some major disadvantages, such as: they require frequent site visits for refueling and maintenance, and furthermore diesel fuel is often expensive and not readily available in rural areas of many developing countries. The consumption of fossil fuels also has an environmental impact, in particular the release of carbon dioxide (CO2) into the atmosphere. CO2 emissions can be greatly reduced through the application of renewable energy technologies, which are already cost competitive with fossil fuels in many situations. Good examples include large-scale grid-connected wind turbines, solar water heating, and off-grid stand-alone PV systems [1]. The use of renewable energy for water pumping systems is, therefore, a very attractive proposition. Windmills are a long-established method of using renewable energy; however they are quickly phasing out from the scene despite success of large scale grid-tied wind turbines. PV systems are highly reliable and are often chosen because they offer the lowest life-cycle cost, especially for applications requiring less than 10KW, where grid electricity is not available and where internal-combustion engines are expensive to operate [1]. If the water source is 1/3 mile (app. 0.53K*m*) or more from the power line, PV is a favorable economic choice [2].

A great deal of research has been done to improve the efficiency of the PV modules. A number of methods of how to track the maximum power point of a PV module have been proposed to solve the problem of efficiency and products using these methods have been manufactured and are now commercially available for consumers [3]. As the market is now flooded with varieties of these MPPT that are meant to improve the efficiency of PV modules under various insulations conditions it is not known how many of these can really deliver on their promise under a variety of field conditions.

In our research, the primary goal was to develop an efficient cost effective water pumping system run by solar power, which will be optimized specially for the rural areas of Bangladesh. In doing so firstly we tried to use minimum number of components to minimize cost and losses. Then investigated if the MPPT that are said to be highly efficient and do track the true maximum power point under the various conditions in a country like Bangladesh [3].

In our research, the Boost converter is not considered as it is inferior than others while proving large initial current reducing the voltage lower than its input, which is very much desired at starting.

2 Design Consideration

To develop a cost effective solar powered pumping system following points are taken in to consideration.

2.1 Alternative Storage: Excluding the battery

Needless to say, photovoltaic are able to produce electricity only when the sunlight is available, therefore stand-alone systems obviously need some sort of backup energy storage which makes them available through the night or bad weather conditions. The most popular solution of using batteries has a

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number of disadvantages. The type of lead-acid battery suitable for PV systems is a deep-cycle battery [4], which is different from one used for automobiles, and it is more expensive and not widely available. Battery lifetime in PV systems is typically three to eight years, but this reduces to typically two to six years in hot climate since high ambient temperature dramatically increases the rate of internal corrosion [3]. Batteries also require regular maintenance and will degrade very rapidly if the electrolyte is not topped up and the charge is not maintained. They reduce the efficiency of the overall system due to power loss during charge and discharge. Typical battery efficiency is around 85% but could go below 75% in hot climate [3]. From all those reasons, experienced PV system designers avoid batteries whenever possible. The additional cost of reservoir is considerably lower than that incurred by the battery equipped system.

2.2 The use of DC pump: excluding the inverter

It helps in two stages i) exclusion of inverter thus reducing price significantly ii) A robust load matching using maximum power transfer theorem.

2.3 MPPT tracking

When a PV module is directly coupled to a load, the PV module's operating point will be at the intersection of its *I–V* curve and the load line which is the *I-V* relationship of load. For the equivalent circuit in Figure 3-1, a resistive load has a straight line with a slope of $1/R_{load}$ as shown in Figure 3-2. In other words, the impedance of load dictates the operating condition of the PV module.

In general, this operating point is seldom at the PV module's MPP, thus it is not producing the maximum power. A study shows that a direct-coupled system utilizes a mere 31% of the PV capacity. A PV array is usually oversized to compensate for a low power yield during winter months. This mismatching between a PV module and a load requires further over-sizing of the PV array and thus increases the overall system cost. To mitigate this problem, a maximum power point tracker (MPPT) can be used to maintain the PV module's operating point at the MPP. MPPTs can extract more than 97% of the PV power when properly optimized [6].

2.4 Choosing the Best MPPT Tracker

A MPPT is used for extracting the maximum power from the solar PV module and transferring that power to the load [8, 9].

The heart of MPPT hardware is a switch-mode DC-DC converter. It is widely used in DC power supplies and DC motor drives for the purpose of converting unregulated DC input into a controlled DC output at a desired voltage level [10]. MPPT uses the same converter for a different purpose: regulating the input voltage at the PV MPP and providing load matching for the maximum power transfer.

Many MPPT techniques have been proposed in the literature; example are the Perturb and Observe (P&O) methods [8, 11-14], Incremental Conductance (IC) methods [6, 12], Fuzzy Logic Method [8, 11, 15], etc. In this paper two most popular of MPPT technique (Perturb and Observe (P&O) methods and Incremental Conductance methods) and three of different DC-DC converters (Buck, Boost and Cuk converter) are compared to get the optimum solution of MPPT.

3 DC-DC CONVERTERS

3.1 Buck Converter

The buck converter can be found in the literature as the step down converter [5]. This gives a hint of its typical application of converting its input voltage into a lower output voltage, where the conversion ratio $M = V_o/V_{in}$ varies with the duty ratio D of the switch [4, 5].

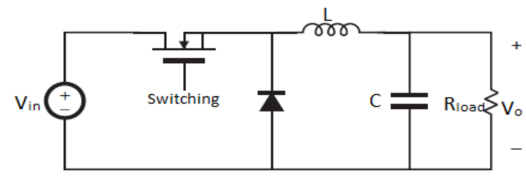

Fig. 1. Equivalent circuit of a Buck converter.

D=Duty cycle;
$V_o/V_{in}=D$; $I_o/I_{in}=1/D$; So, from these two equations,
$R_{in}= V_{in}/I_{in}= (1/D^2) \times (V_o/I_o) = (1/D^2) \times R_{load}$;

3.2 Boost Converter

The boost converter is also known as the step-up converter. The name implies it's typically application of converting a low input voltage to a high output voltage, essentially functioning like a reverse buck converter.

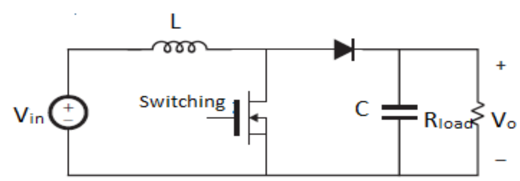

Fig. 2. Equivalent circuit of a Boost converter.

D=Duty cycle; $V_o/V_{in}=1/(1\text{-}D)$;
$I_o/I_{in}=1\text{-}D$; So, from these two equations,
$R_{in}= V_{in}/I_{in}= (1\text{-}D^2) \times (V_o/I_o) = (1\text{-}D^2) \times R_{load}$;

3.3 Buck-Boost Converter

It's the combination of Buck & Boost as follows

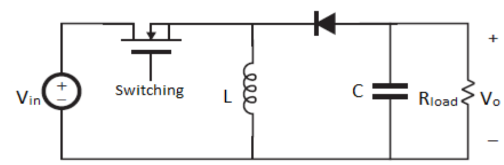

Fig. 3. Equivalent circuit of a Buck-Boost converter.

Now, D=Duty cycle; $V_o/V_{in}=D/(1\text{-}D)$;

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I_o / I_{in}=(1-D) / D; So, from these two equations,
$R_{in} = V_{in}/I_{in} = [D^2/(1-D^2)] \times (V_o/I_o) = [D^2/(1-D^2)] \times R_{load}$;

3.4 Cuk Converter

Please The Cuk converter uses capacitive energy transfer and analysis is based on current balance of the capacitor. Cuk converter will responsible to invert the output signal from positive to negative or vice versa.

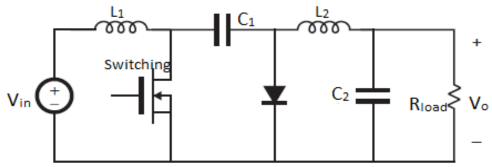

Fig. 4. Equivalent circuit of a Cuk converter.

Now, D=Duty cycle; V_o / V_{in}=D / (1-D);
I_o / I_{in}=(1-D) / D; So, from these two equations,
$R_{in} = V_{in}/I_{in} = [D^2/(1-D^2)] \times (V_o/I_o) = [D^2/(1-D^2)] \times R_{load}$;

4 Simulation Consideration

According to Irradiance data of Bangladesh, it varies from 200W / m^2 to 1000W / m^2 at day time from 6 am to 6 pm in the month of June [16]. In our simulation we have simulated the circuit for 5 different stages in this range. The solar panel taken in consideration has specification as in Table 1.

TABLE 1
Pv Panel Specification

Electrical Characteristics	
Maximum Power (P_{max})	150W
Voltage at P_{max} (V_{mp})	34.55 A
Current at P_{max} (I_{mp})	4.35A
Open-circuit voltage (V_{oc})	43.5V
Short-circuit current (I_{sc})	4.75A
Temperature coefficient of I_{sc}	0.065±0.015 % / °C
Temperature coefficient of V_{oc}	-160±20 mV / °C
Temperature coefficient of power	-0.5±0.05 % / °C
NOCT	47±2°C

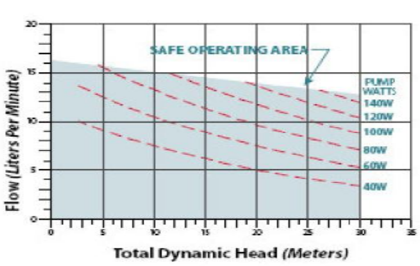

Fig. 5. Kyocera SD 12-30 water pump performance chart [2].

The DC pump can be characterized by following equation as per the Simulink simulation results.

$$R_{load} = 9.5 \times 10^{-5}.V_o^3 - 8.7 \times 10^{-3}.V_o^2 + 0.37.V_o + 0.2$$

TABLE 2
Converter Design Specifications

Specification	
Input Voltage (V_{in})	20-48V
Input Current (I_{in})	0-5A (<5% ripple)
Output Voltage (V_o)	12-30V (<5% ripple)
Output Current (I_o)	0-5A (<5% ripple)
Maximum Output Power (P_{max})	150W
Switching Frequency (f)	50Hz
Duty Cycle (D)	$0.1 \le D \le 0.6$

5 Simulation Result

First the capabilities of the three converters are compared to trace the MPPT properly with the variation of input irradiance and also input module voltage.

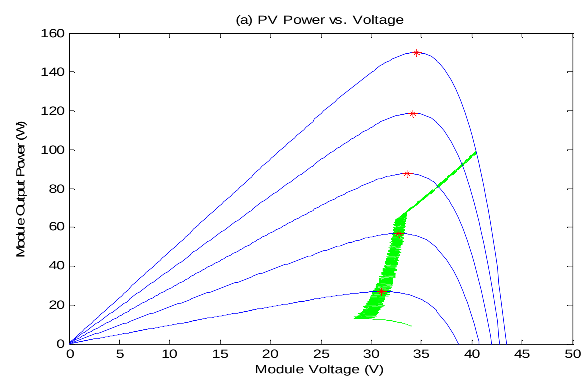

Fig. 6. The MPPT tracking using Buck converter.

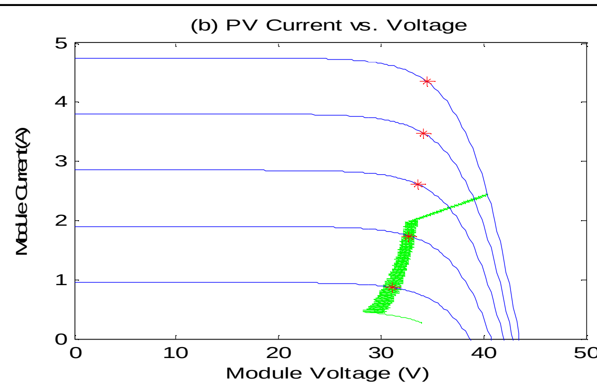

Fig. 7. The MPPT tracking using Buck converter.

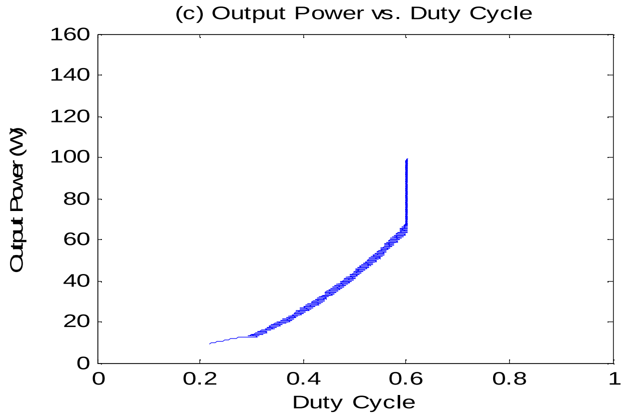

Fig. 8. The output power curve of Buck converter.

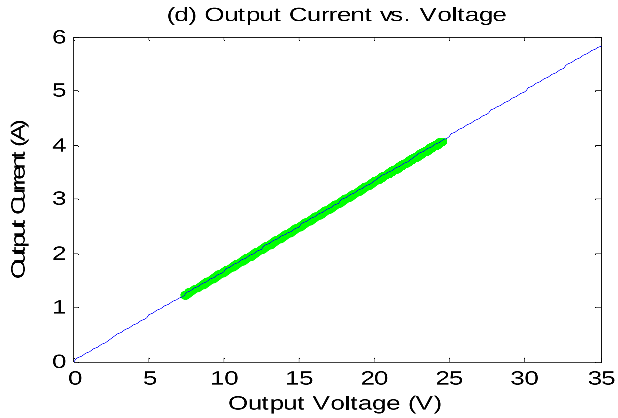

Fig. 9. The output current curve of Buck converter.

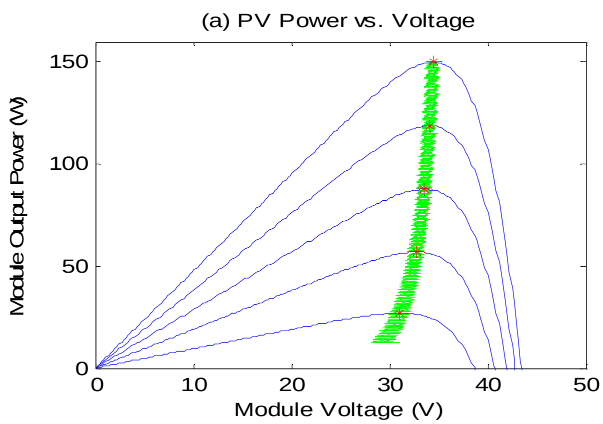

Fig. 10. The MPPT tracking using Buck-Boost converter.

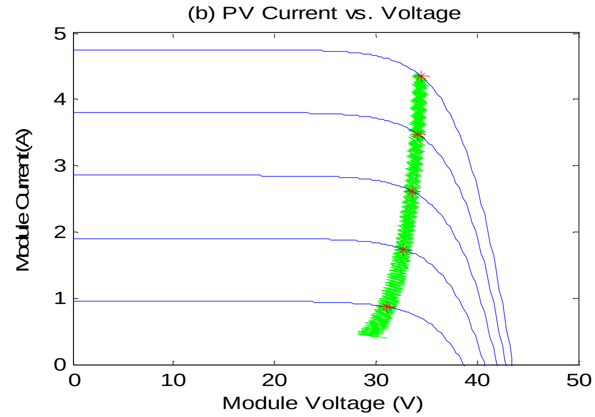

Fig. 11. The MPPT tracking using Buck-Boost converter.

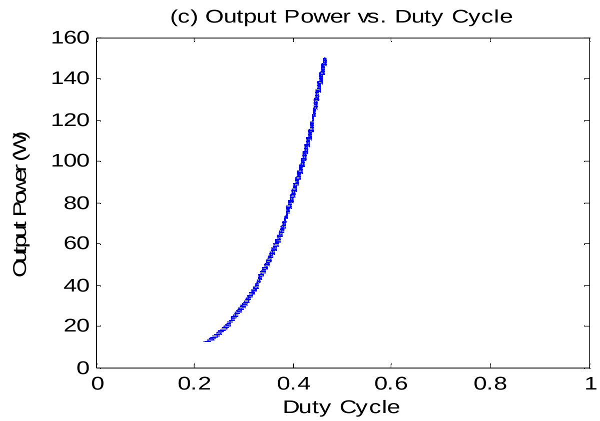

Fig. 12. The output power curve of Buck-Boost converter.

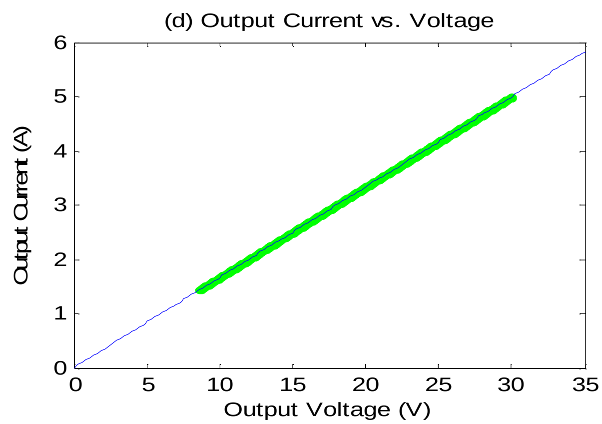

Fig. 13. The output current curve of Buck-Boost converter.

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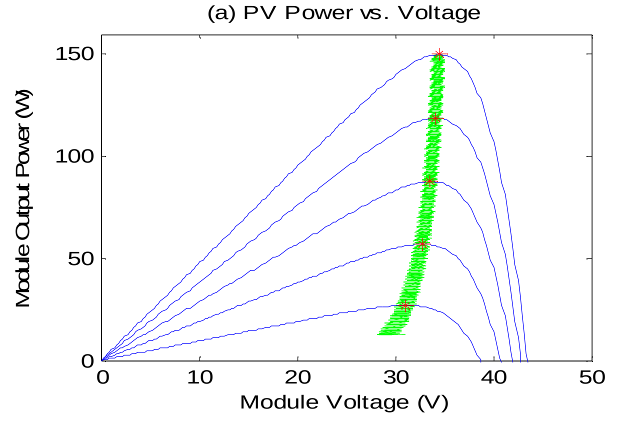

Fig. 14. The MPPT tracking using Cuk converter.

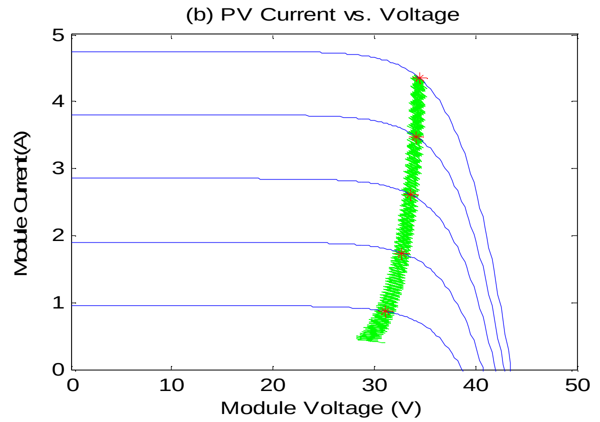

Fig. 15. The MPPT tracking using Cuk converter.

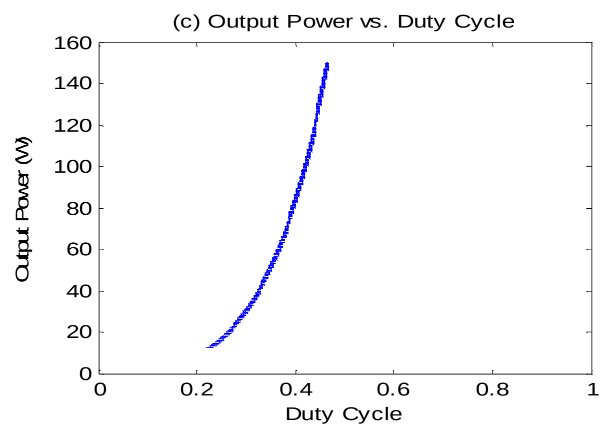

Fig. 16. The output power curve of Cuk converter.

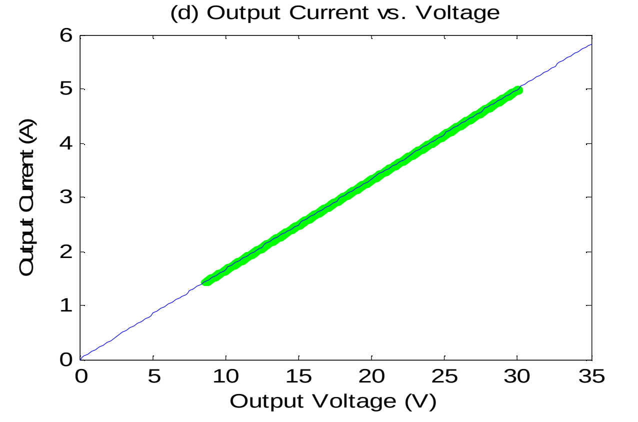

Fig. 17. The output current curve of Cuk converter.

TABLE 3
OUTPUT DATA FOR BUCK CONVERTER

	Irradiance	1000 W/m^2	800 W/m^2	600 W/m^2	400 W/m^2	200 W/m^2
Without MPPT	V_{MPP}	34.5V	34.1V	33.6V	32.7V	31.1V
	I_{MPP}	4.35A	3.48A	2.61A	1.73A	0.87A
	P_{MAX}	150W	118.8W	87.7W	56.9W	26.9W
With MPPT	R_{in}	38.455	18.929	16.667	16.667	16.667
	D	0.3950	0.5630	0.6000	0.6000	0.6000
	V_o	12.667	18.475	22.028	23.453	24.275
	I_o	2.1113	3.0793	3.6714	3.9088	4.0460
	R_{load}	6Ω	6Ω	6Ω	6Ω	6Ω

TABLE 4
OUTPUT DATA FOR BUCK-BOOST CONVERTER

	Irradiance	1000 W/m^2	800 W/m^2	600 W/m^2	400 W/m^2	200 W/m^2
Without MPPT	V_{MPP}	34.5V	34.1V	33.6V	32.7V	31.1V
	I_{MPP}	4.35A	3.48A	2.61A	1.73A	0.87A
	P_{MAX}	150W	118.8W	87.7W	56.9W	26.9W
With MPPT	R_{in}	33.616	18.963	12.527	9.9588	7.9424
	D	0.2970	0.3600	0.4090	0.4370	0.4650
	V_o	12.665	18.475	22.922	26.690	29.998
	I_o	2.1109	3.0793	3.8204	4.4484	4.9997
	R_{load}	6Ω	6Ω	6Ω	6Ω	6Ω

TABLE 5
OUTPUT DATA FOR CUK CONVERTER

	Irradiance	1000 W/m²	800 W/m²	600 W/m²	400 W/m²	200 W/m²
Without MPPT	V_{MPP}	34.5V	34.1V	33.6V	32.7V	31.1V
	I_{MPP}	4.35A	3.48A	2.61A	1.73A	0.87A
	P_{MAX}	150W	118.8W	87.7W	56.9W	26.9W
With MPPT	R_{in}	33.616	18.963	12.527	9.9588	7.9424
	D	0.2970	0.3600	0.4090	0.4370	0.4650
	V_o	12.665	18.475	22.922	26.690	29.998
	I_o	2.1109	3.0793	3.8204	4.4484	4.9997
	R_{load}	6Ω	6Ω	6Ω	6Ω	6Ω

So, we can see that the Buck-Boost converter configuration and Cuk converter configuration is properly tracking the maximum power point but not the buck converter. Figure 6 to figure 17 and table 3 to 5 were obtained by using Matlab coding.

6 CONCLUSION

In this research work, to find out an optimal solution for solar dc pumping system for Bangladesh, we have observed some remarkable findings through simulation to optimize the performance of solar dc pumping. Firstly we have found that to harness the power from solar panel efficiently we can use either the Buck-Boost or Cuk converter to track the MPPT very efficiently. In terms of efficiency and cost-effectiveness the Cuk converter is the best solution. So using a very compact topology of Cuk MPPT tracker followed by the DC motor with proper rating of solar panel can serve the purpose of solar pumping very efficiently. In future we are going to implement the topology to check out the actual throughput of the pump and its effectiveness.

REFERENCES

[1] Thompson, Marry A. *Reverse-Osmosis Desalination of Seawater Powered by Photovoltaics Without Batteries* Doctoral Thesis, Loughborough University, 2003W.-K. Chen, *Linear Networks and Systems.* Belmont, Calif.: Wadsworth, pp. 123-135, 1993. (Book style)

[2] Kyocera Solar Inc. *Solar Water Pump Applications Guide* 2001 (downloaded from www.kyocerasolar.com)

[3] BP Solar *BP SX150 - 150W Multi-crystalline Photovoltaic Module* Datasheet, 2001

[4] Messenger, Roger & Jerry Ventre *Photovoltaic Systems Engineering 2nd Edition* CRC Press, 2003

[5] Masters, Gilbert M. *Renewable and Efficient Electric Power Systems* John Wiley & Sons Ltd, 2004

[6] Hohm, D. P. & M. E. Ropp "Comparative Study of Maximum Power Point Tracking Algorithms" *Progress in Photovoltaics: Research and Applications* November 2002, page 47-62

[7] Hua, Chihchiang, Jongrong Lin & Chihming Shen "Implementation of a DSPControlled Photovoltaic System with Peak Power Tracking" *IEEE Transactions on Industrial Electronics, Vol. 45, No. 1* February 1998, page 99-107

[8] Dang, Thuy Lam *A Digitally-controlled Power Tracker* Master's Thesis, California Polytechnic State University, Pomona, 1990

[9] Day, Christopher Alan *The Design of an Efficient, Elegant, and Cubic Pico-Satellite Electronics System* Master's Thesis, California Polytechnic State University, San Luis Obispo, 2004

[10] Mohan, Undeland, Robbins *Power Electronics – Converters, Applications, and Design 3rd Edition* John Wiley & Sons Ltd, 2003

[11] Enslin, John H., Mario S. Wolf, Daniël B. Snyman, & Wernher Swiegers "Integrated Photovoltaic Maximum Power Point Tracking Converter" *IEEE Transactions on Industrial Electronics, Vol. 44, No. 6* December 1997, page 769-773

[12] Green, Martin A. *Solar Cells; Operating Principles, Technology, and System Applications* Prentice Hall Inc., 1982

[13] Hart, Daniel W. *Introduction to Power Electronics* Prentice Hall Inc., 1996

[14] Hohm, D. P. & M. E. Ropp "Comparative Study of Maximum Power Point Tracking Algorithms" *Progress in Photovoltaics: Research and Applications* November 2002,page 47-62

[15] Castañer, Luis & Santiago Silvestre *Modelling Photovoltaic Systems, Using PSpice* John Wiley & Sons Ltd, 2002

[16] Hussain,M. etal. "Final Report of Solar and Wind Energy Resource Assessment (SWERA) – Bangladesh", 2007