



DESIGN AND IMPLEMENTATION OF SOLAR POWERED WATER PUMPING SYSTEM

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ABSTRACT: The utilization of a cuk converter for control of photovoltaic power using Maximum Power Point Tracking (MPPT) control mechanism is presented in this paper. The main aim of the project is to use cuk converter along with a Maximum Power Point Tracking control mechanism. The MPPT is responsible for extracting the maximum possible power from the photovoltaic panel and feeding it to the load via the cuk converter which steps up and steps down the voltage to required magnitude. Both the cuk converter and the solar panel are modeled using Sim Power Systems block in MATLAB Simulink software. The analysis of photovoltaic panel, cuk converter system is presented and the MATLAB/SIMLINK model is demonstrated and simulated for a typical 30W solar panel.

Keywords - Renewable energy, Photovoltaic system, Cuk converter, Maximum power point tracking.

I INTRODUCTION

The most important aspect of a solar cell is that it generates electrical potential from solar energy through the solar photovoltaic module, made up of silicon cells. Although each cell outputs a relatively low voltage, if many are connected in series/parallel combination a solar photovoltaic array is formed. In a typical module, there can be up to 36 solar cells, producing an open circuit voltage of about 21V. At a given temperature and insolation level, PV cells supply maximum power at one particular operation point depend on the load called the maximum power point (MPP). There are various DC-DC converter topologies such as buck, boost, buck-boost and cuk converters connected with solar PV application. In this paper, duty cycle of cuk converter is controlled by pulse with modulated signal generated from microcontroller based MPPT. An analytical model of the solar PV module developed under different temperature and insolation is simulated, tested and verified. Further, a cuk converter and PV panel array is modeled and tested under different conditions.

Water pumps are driven by various types of motors. AC induction motors are cheaper and widely available worldwide. The system, however, needs an inverter to convert DC output power from PV to AC power, which is usually expensive. In general, DC motors are used because they are highly efficient and can be directly coupled with a PV module or array.

II THE PROPOSED SYSTEM

The experimental water pumping system proposed in this project is a stand-alone type without backup batteries. The system is very simple and consists of a single PV module, a maximum power point tracker (MPPT), and a DC water pump.

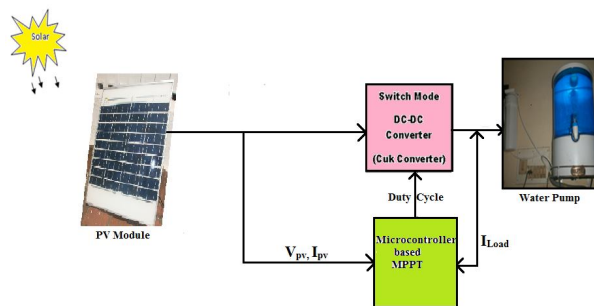


Fig.1. Proposed block diagram of PV water pumping system

MODELING OF PV CELL

The simplest model of a PV cell is shown in Fig.2 as an equivalent circuit below that consists of an ideal current source in parallel with an ideal diode. The current source represents the current generated by photons (often denoted as I_{ph} or I_L), and its output is constant under constant temperature and constant incident radiation of light.

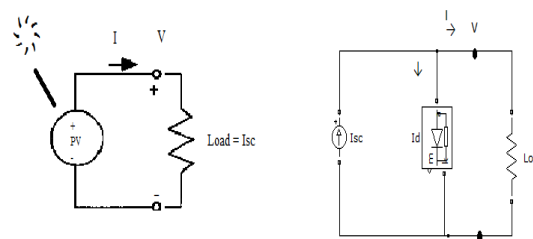
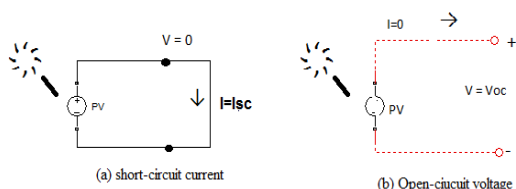


Fig.2. PV cell with a load and its simple equivalent circuit

There are two key parameters frequently used to characterize a PV cell. Shorting together the terminals of the cell, as shown in Fig.3.(a), the photon generated current will follow out of the cell as a short-circuit current (I_{sc}). Thus, $I_{ph} = I_{sc}$. As shown in Fig. 3 (b), when there is no connection to the PV cell (open-circuit), the photon generated current is shunted

internally by the intrinsic p-n junction diode. This gives the open circuit voltage (V_{oc}). The PV module



or cell manufacturers usually provide the values of these parameters in their datasheets

Fig.3. Short-circuit and an Open-circuit condition

The output current (I) from the PV cell is found by applying the Kirchoff's current law (KCL) on the equivalent circuit shown in Fig. 3.

$$I = I_{sc} - I_d \tag{1}$$

where: I_{sc} is the short-circuit current that is equal to the photon generated current, and I_d is the current shunted through the intrinsic diode.

The diode current I_d is given by the Shockley's diode equation:

$$I_d = I_0 (e^{qV_d/kT}) \tag{2}$$

where: I_0 is the reverse saturation current of diode (A),

q is the electron charge (1.602×10^{-19} C),

V_d is the voltage across the diode (V),

k is the Boltzmann's constant (1.381×10^{-23} J/K),

T is the junction temperature in Kelvin (K).

$$\frac{qV_d}{kT} = 38.9V_d$$

$$I_d = I_0 (e^{38.9V_d} - 1) \text{ at } 25^\circ\text{C}$$

Replacing I_d of the equation (1) by the equation (2) gives the current-voltage relationship of the PV cell.

$$I = I_{sc} - I_0 (e^{qV/kT} - 1) \tag{3}$$

where: V is the voltage across the PV cell, and I is the output current from the cell.

The reverse saturation current of diode (I_0) is constant under the constant temperature and found by setting the open-circuit condition as shown in Fig.3 (b). Using the equation (2), let $I = 0$ (no output current) and solve for I_0 .

$$0 = I_{sc} - I_0 (e^{qV_d/kT} - 1)$$

$$I_{sc} = I_0 (e^{qV_d/kT} - 1)$$

$$I_0 = \frac{I_{sc}}{(e^{qV_d/kT} - 1)}$$

The photon generated current, which is equal to I_{sc} , is directly proportional to the irradiance, the intensity of illumination, to PV cell.

MODELING A PV MODULE BY MATLAB

The 30W PV module shown in Fig.4, is chosen for a MATLAB simulation model. The module is made of 36 multi-crystalline silicon solar cells in series and provides 30W of nominal maximum power. Table 1 shows its electrical specification.



Fig.4. 30W solar panel

Electrical Characteristics	
Maximum Power (P_{max})	30W
Voltage at P_{max} (V_{mp})	17.7V
Current at P_{max} (I_{mp})	1.7A
Open-circuit voltage (V_{oc})	21.6V
Short-circuit current (I_{sc})	1.93A

Table.1. Electrical characteristics data of PV module

The model consists of a current source (I_{sc}), a diode (D), and a series resistance (R_s) and load. To make a better model, it also includes temperature effects on the short-circuit current (I_{sc}) and the reverse saturation current of diode (I_0). It uses a single diode with the diode ideality factor (n) set to achieve the best I-V curve match.

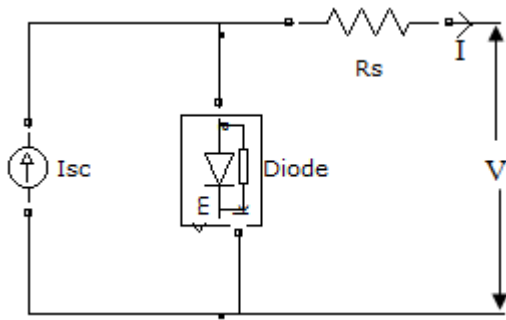


Fig.5. Equivalent circuit used in the MATLAB simulations

The equation that describes the current-voltage relationship of the PV cell, and it is shown below.

$$I = I_{sc} - I_d$$

$$= I_{sc} - I_o [e^{qV_d/KT} - 1]$$

$$V_d = V + IR_s$$

$$I = I_{sc} - I_o [e^{q/KT(V + IR_s)} - 1]$$

where,

$$I_{sc} = 2A$$

$$I_o = 1.0 \times 10^{-9}A$$

$$R_s = 0.05\Omega$$

$$\frac{qT}{K} = 26 \times 10^{-3}$$

$$I_d = 1.0 \times 10^{-9}[\exp (v + 0.05I / (26 \times 10^{-3}) - 1)]$$

For 36 cell,

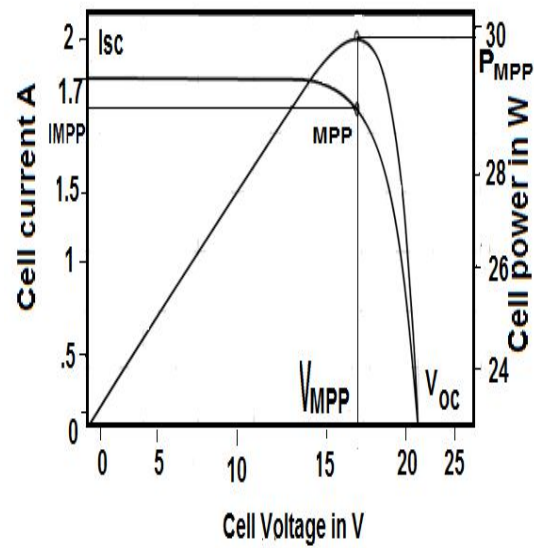
$$I_d = 1.0 \times 10^{-9}[\exp (36u (1) + 0.05u (2) / (26 \times 10^{-3}) - 1]$$

$$U(1) = V_{pv}$$

$$U(2) = I$$

THE I-V, P-V CURVE AND MAXIMUM POWER POINT

The I-V and P-V curve of the 30W PV module simulated with the MATLAB model. A PV module can produce the power at a point, called an operating point, anywhere on the I-V curve. The coordinates of the operating point are the operating voltage and current. There is a unique point near the knee of the I-V curve, called a maximum power point (MPP), at which the module operates with the maximum efficiency and produces the maximum output power. The power vs voltage plot is overlaid on the I-V plot of the PV module, as shown in Fig 6. It reveals that the amount of power produced by the PV module varies greatly depending on its operating condition. It is important to operate the system at the MPP of PV module in order to exploit the



maximum power from the module.

Fig.6. I-V and P-V relationships of 30W PV module graph with originpro8 software

III MODEL OF DC-DC CONVERTER

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. 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. The initial condition is when the input voltage is turned on and switch (Q_1) is off. The diode (D) is forward biased, and the capacitor (C_1) is being charged. The operation of circuit can be divided into two modes. Mode 1: When Q_1 turns ON, the circuit becomes one shown in Fig 7.

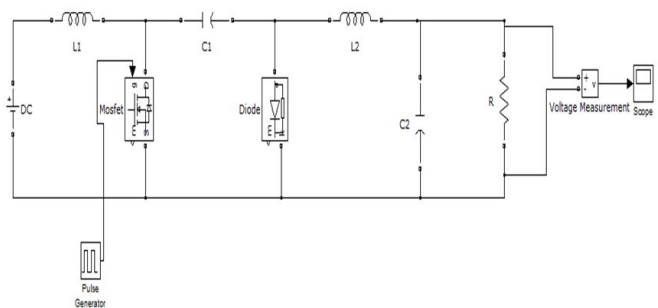


Fig.7. Circuit diagram of the basic buck converter

BASIC OPERATION OF CUK CONVERTER

The initial condition is when the input voltage is turned on and switch (Q₁) is off. The diode (D) is forward biased, and the capacitor (C₁) is being charged. The operation of circuit can be divided into two modes. Mode 1: When Q₁ turns ON, the circuit becomes one shown in Fig. 8.

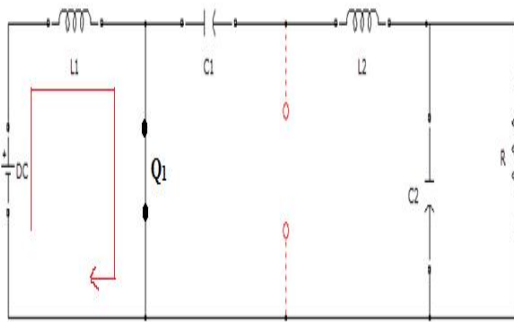


Fig.8. Cuk converter in mode 1.

The transistor Q₁ is turned on at time t = 0. The current flows in the path DC supply Vs, L₁ and Q₁. The inductor current rises from I_{L1} to I_{L2} at time t = t₁. Voltage in capacitor C₁ is discharged in path C₁, Q₁, C₂ and L₂.

Mode 2: When Q₁ turns OFF, the circuit becomes one shown in Fig. 9.

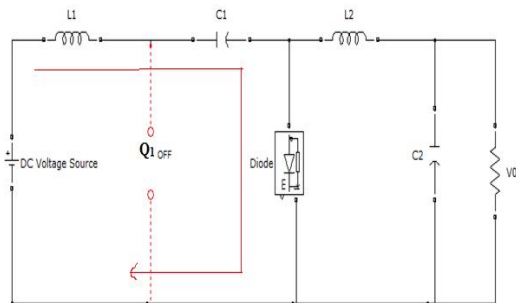


Fig.9. cuk converter in mode 2

When transistor Q₁ is turned off at time t = t₁. The capacitor C₁ is charged from the input supply and the energy stored in L₂ is transferred to the load. The current in L₁ falls from I_{L2} to I_{L1} in time t₂ in the path Vs, L₁, C₁ and D. The output voltage of the cuk converter is given by,

$$V_0 = - \frac{V_s \times D}{1-D}$$

Where V_s = Input voltage
 D = Duty cycle

IVCUK CONVERTER DESIGN

Here, a cuk converter is designed based on the specification shown in the table below. After component selection, the design is simulated in MATLAB.

Specification	
Input Voltage (V _s)	18V
Input Current (I _s)	0-2A (< 5% ripple)
Output Voltage (V _o)	12-30V (< 5% ripple)
Output Current (I _o)	0-2A (< 5% ripple)
Maximum Output Power (P _{max})	30W
Switching Frequency (f)	50KHz
Duty Cycle (D)	0.1 to 0.6

Table.2. Design specification of the Cuk Converter

V_s=18V f=50KHZ D=0.6 I_s=1.7

Output voltage:

$$V_0 = - \frac{V_s \times D}{1-D}$$

$$V_0 = \frac{-18 \times 0.6}{1-0.6} = -27V$$

Assumption: ΔiL = 0.05 × 1.7 = 0.085A

$$L_1 = \frac{V_s \times D}{\Delta i_L \times f} = \frac{18 \times 0.6}{0.085 \times 50 \times 10^3} = 2.25mH$$

$$L_2 = \frac{V_s \times D}{\Delta i_L \times f} = \frac{18 \times 0.6}{0.085 \times 50 \times 10^3} = 2.25mH$$

$$R = \frac{V_0 \times V_s}{P_0} = \frac{27 \times 17}{30} = 24\Omega$$

$$C_1 = \frac{V_0 \times D}{R \times f \times \Delta V_{C1}} = \frac{27 \times 0.6}{24 \times 50000 \times 0.25} = 6\mu F$$

$$C_2 = \frac{1-D}{R \times I_{L2} \times \Delta V_{C2}} = \frac{1-0.6}{24 \times 2.25 \times 10^{-2} \times 50 \times 10^3} \times \frac{1}{0.05} = 0.50\mu F$$

V_o = 27V , L₁ = 2.25mH , L₂ = 2.25mH , C₁ = 6.0 uF ,

C₂ = 0.5 uF

V SIMULATION RESULTS

The following section describes simulation of the PV model using MATLAB. The modeling and simulation of whole system has been done in the MATLAB-SIMULINK environment. Fig. 10 shows building blocks PV panel which are used to derived the V-I characteristics also the MPP for various insolation level determined the voltage and current

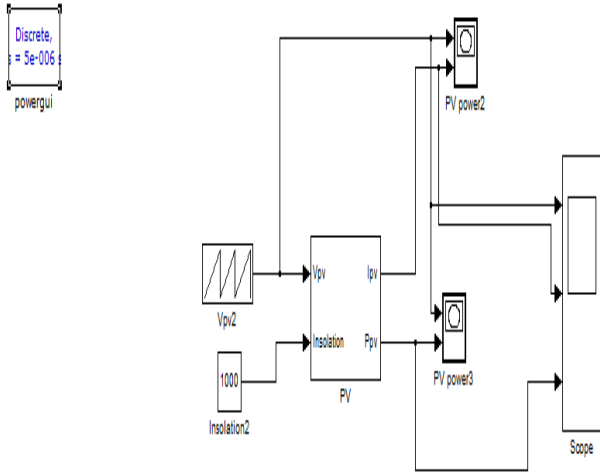


Fig.10. Simulation of PV model

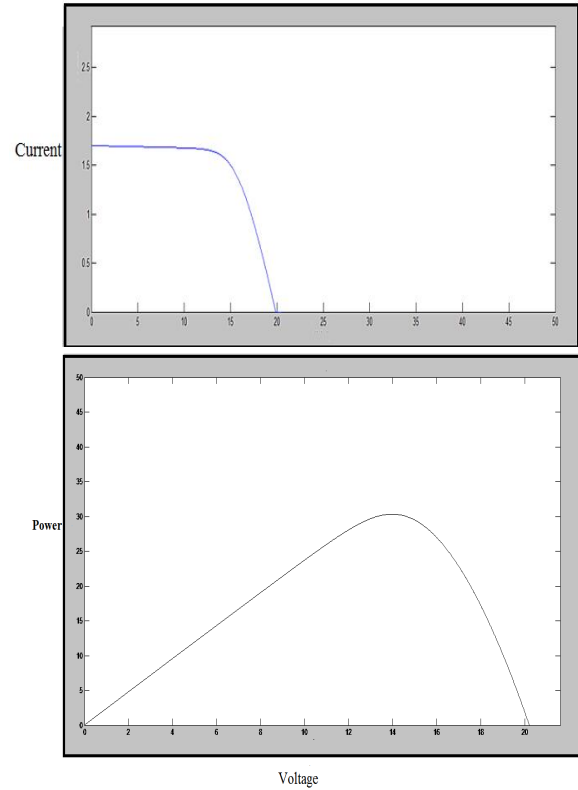


Fig.12 (a) V-I Characteristics of PV model (b) P-V characteristics of PV model

Fig.13 shows the MATLAB for the solar panel array.

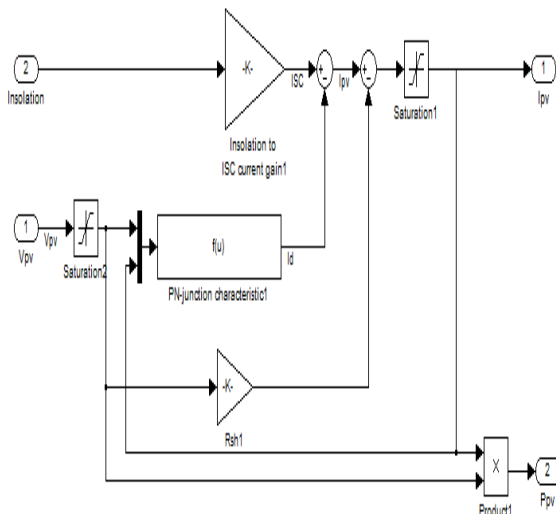


Fig.11. Block diagram of PV sub model

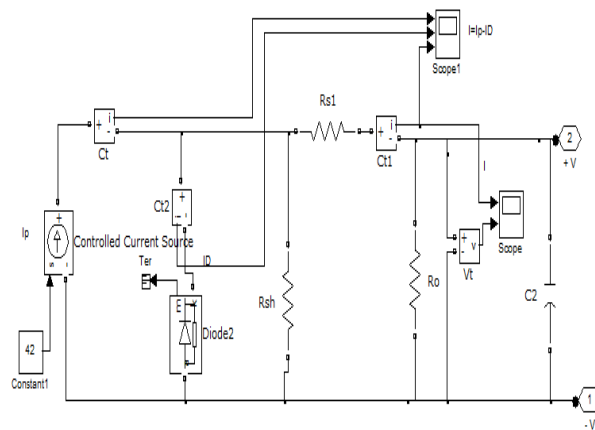


Fig.13. Equivalent circuit for solar panel

Fig.14. (a) and (b) shows the solar panel array connected to the cuk converter and the output voltage.

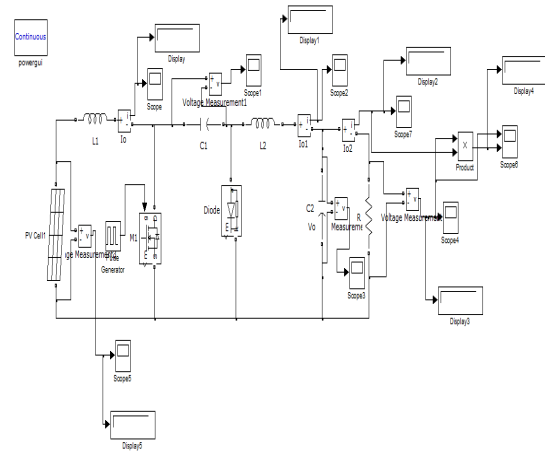


Fig.14. (a) Solar panel connected with cuk converter

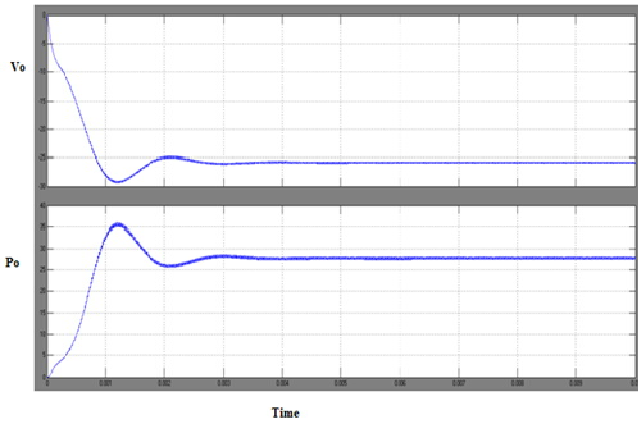


Fig.14. (b) Output voltage and power of cuk converter

Table 3: Summarizes the MPPT operating point for determined after varying the duty cycle of the cuk converter from 0.4 to 0.6

PV Module Parameters			Cuk Converter Parameters				
V_{MPP}	I_{MPP}	P_{max}	R_{in}	D	V_0	I_0	R_{load}
17.7V	1.7A	30W	10.4 Ω	0.6	26.5V	1.13A	24 Ω
17.5V	1.2A	21W	14.7 Ω	0.54	20V	1.08A	24 Ω
15V	0.8A	12W	18.7 Ω	0.5	15V	0.8A	24 Ω
12V	0.6A	7.2W	20 Ω	0.45	11.5V	0.69A	24 Ω

Table 3: System operation for various duty cycles

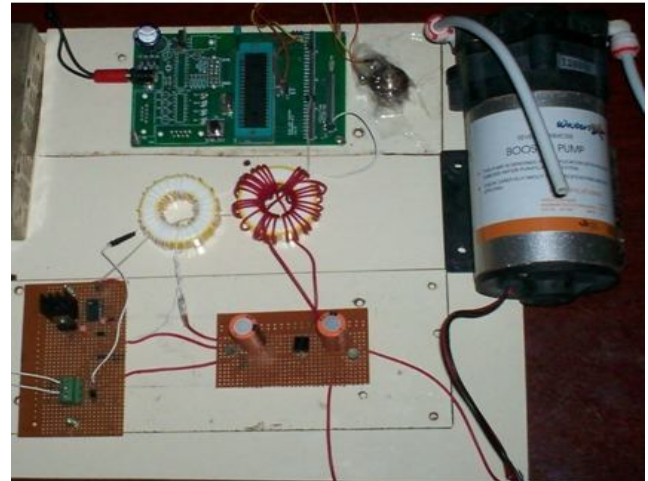


Fig.15 Shown the experimental setup for the cuk converter connected to a DC pump.

Fig.15. Hardware prototype with DC pump load



Fig.16. Water pump load



Fig.17. Pulse generation for 20% duty cycle

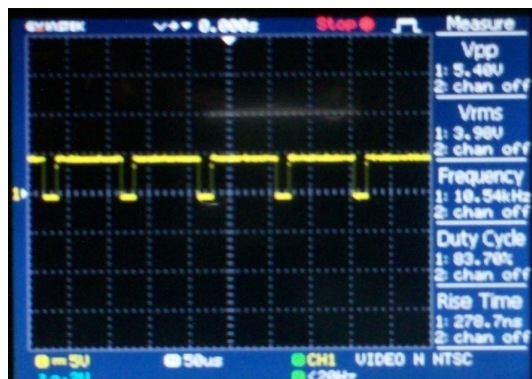


Fig.18. Pulse generation for 80% duty cycle



Fig.19. DC Voltage Output

VI CONCLUSION

This study presents a simple but efficient photovoltaic water pumping system. It models each component and simulates the system using MATLAB. In PV model, the V-I and P-I characteristics curve plot from the given experimental data and simulated using MATLAB. By connecting Solar panel to cuk converter and by changing the duty cycle step by step, the point at which maximum power extraction occurs can be plotted. At various duty cycles only one duty cycle provide maximum power close to 30W. The result show the MPPT operating point of PV panel array occurs at 60% of duty cycle of cuk converter.

REFERENCES

- [1]. Kashif Ishaque, Zainal Salam, "An Improved Particle Swarm Optimization (PSO)-Based MPPT for PV Wit Reduced Steady State Oscillation" IEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 27, NO. 8,AUGUST 2012.
- [2]. MUMMADI VEERACHARY, "Fourth-Order Buck Converter for Maximum Power Point Tracking Applications" IEEE TRANSACTIONS ON AEROSPACE

AND ELECTRONIC SYSTEMS VOL. 47, NO. 2 APRIL 2011.

[3]. Azadeh Safari and Saad Mekhilef, "Simulation and Hardware Implementation of Incremental Conductance MPPT With Direct Control Method Using Cuk Converter" I IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 58, NO. 4, APRIL 2011.

[4]. Chian-Song Chiu, "T-S Fuzzy Maximum Power Point Tracking Control of Solar Power Generation system" IEEE TRANSACTIONS ON ENERGY CONVERSION,VOL. 25, NO. 4, DECEMBER 2010

[5]. A.Daoud and A.Midoun, "Maximum Power Point tracking techniques for solar water pumping system" IEEE TRANSACTIONS Septembre 2010

[6]. M.I.Chergui ,M.Bourahla "Simulation of the Photovoltaic Pumping System Control" IEEE TRANSACTIONS November 2010

[7].Taufik,Akihiro "Modeling and simulation of Photovoltaic water pumping system"2009 Third Asia International Conference on Modeling & Simulation

[8].BP Solar BP SX150 - 150W Multi-crystalline Photovoltaic Module Datasheet, 2001 [2] Castañer, Luis & Santiago Silvestre *Modelling Photovoltaic Systems, Using PSpice* John Wiley & Sons Ltd, 2002

[9] Chapin, D. M., C. S. Fuller, & G. L. Pearson, Bell Telephone Laboratories, Inc., Murray Hill, New Jersey "A New Silicon p-n Junction Photocell for Converting Solar Radiation into Electrical Power" *Journal of Applied Physics, Volume 25, Issue 5, May 1954, page 676-677*

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