Design and implementation of direct driven solar water pumping system

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Abstract : The deficit in electricity and high diesel costs affects the pumping requirements of community water supplies and irrigation, so using solar energy for water pumping is a promising alternative to conventional electricity and fuel based pumping systems. The main objective of this paper is to present a comprehensive review of solar pumping technology, evaluate the economic viability and impediments in the widespread propagation of solar water pumping systems and technology. In this paper charge controller is simulated using PWM technique for getting constant DC power from PV module.This paper also proposes a cost effective prototype model of soar pumping system which gives constant power irrespective of the irradiation level.

***IndexTerms* – PV Module, Pumping system, PWM, Charge Controller**

I. INTRODUCTION

Renewable energy sources in general, and Solar Energy source in particular, has the potential to provide energy that can be converted into electricity. The solar energy is abundant and no other source in renewable energy is like solar energy. The solar-powered pumping system can be used anywhere but it is appropriate for rural areas which is facing energy crisis. Due to geographical position, regions in India have ample sunshine throughout the year which makes it ideal location for utilization of solar energy. Small farms, villages, and animal herds in developing countries require hydraulic output power of less than a kilowatt. Many of these potential users are too far from an electrical grid to economically tap that source of power, and engine-driven pumping tends to be prohibitively expensive as well as unreliable due to the high cost of purchased fuel, insufficient maintenance and repair capabilities. A solar-powered pump is a normal pump with an electric motor. Electricity for the motor is generated on-site through a solar panel which converts solar energy to direct-current (DC) electricity. Because the nature of the electrical output from a solar panel is DC, a solar-powered pump requires a DC motor if it is to operate without additional electrical components. If a pump has an alternating-current (AC) motor, an inverter would be required to convert the DC electricity produced by the solar panels to AC electricity. Due to the increased complexity and cost, the reduced efficiency of an AC system, most solar-powered pumps have DC motors. DC motor has been used to drive solar energy water pump system

Various researchers have proposed various techniques for implementation of solar pumping system which shows the need to use non-conventional energy resources. [1]Has proposed a solar energy based automated water pumping system which can be used in many villages as an alternative to the fossil fuel based water pumping systems. The system is automated; the water pumps are switched on only when the moisture content of the soil is below a critical level which is determined by the moisture sensors planted in the fields. [2] Has proposed a topology which utilizes a solar photovoltaic (SPV) array that converts the solar energy into electrical energy. The energy obtained is used to drive the PMSM using a 3- phase voltage source inverter. The speed of PMSM is controlled in vector control using a hybrid proportional integral controller. The authors have proposed a design of a single-stage single-switch dc/dc converter for a PV-battery powered water pump system with experimental verification. By using the variable frequency control, the main functions such as MPPT and driving the motor with specific speed can be realized with reduced number of active switches and without sacrificing the overall efficiency as compared to conventional two-stage design [3]. In this paper authors deals with the stand alone solar PV (Photo Voltaic) supplied PMSM (Permanent Magnet Synchronous Motor) drive for water pumping system. An interlink Boost converter is used between solar PV panel and DC bus of PMSM drive The DC bus voltage of PMSM drive is maintained constant by controlling the duty cycle of boost converter. Three phase VSI (Voltage Source Inverter) is controlled to supply PMSM under change in solar irradiation to regulate discharge of water [4]. In this paper the authors have proposed a PV-water pumping scheme has been validated through a demonstration of its various steady state, starting and dynamic performances. The performance of the system has been simulated using the MATLAB toolboxes, and implemented on an experimental system. The DC link voltage and motor phase current sensing elements have been absolutely eliminated, resulting in a simple and cost-effective drive. The VSI has adopted a fundamental frequency switching, offering an enhanced efficiency due to the reduced switching losses in VSI [5]. [6] Proposes a simple, cost effective and efficient brushless DC (BLDC) motor drive for solar photovoltaic (SPV) array fed water pumping system. A zeta converter is utilized in order to extract the maximum available power from the SPV array. The proposed control algorithm eliminates phase current sensors and adapts a fundamental frequency switching of the voltage source inverter (VSI), thus avoiding the power losses due to high frequency switching. [7] Has proposed a technique for the identification of the maximum power point (MPP) based on fuzzy logic. This method is used to generate the cyclic ratio to operate the switcher within the maximum power of a photovoltaic array (PVA)

The need of water in rural areas is very high for the purpose of agriculture and other domestic uses. Compared to cities where huge pipelines are used for transportation of water, rural areas still opt for pumping water from the well. Keeping in view the shortage of power in rural and remote areas, water pumping must be evolved in order to overcome this problem of electricity shortage. Thus water pumping has become a promising application of PV energy. So the main contributions of this paper are:

1. To simulate open loop and closed loop PWM based charge controller to provide constant DC power.
2. To implement direct driven solar water pumping system using Solar charge controller with PWM technique

II. PROPOSED SYSTEM OPERATION AND DESIGN

The simple purpose of the solar charge controller is to essentially maintain the charge coming from the solar panel to the battery bank and ensuring that the battery don't overcharge and it is charged as best as it can. The solar charge controller goes between the solar panel and deep cycle batteries. A charge controller is an important component in a battery based system. It is not used in a direct driven system as they do not have the batteries to charge. The primary role is to manage charging the battery bank. It prevents it from overcharging and many of them control the rate of current and voltage to which it charges. Some charge controllers have load control where DC load is directly connected to the controller instead of connecting it to battery enabling it to turn ON and OFF based on voltage to the battery and over the time of day, for example the solar charge controller will turn the load OFF if the battery gets to low or will turn of ON from dusk to dawn. At night the voltage of the battery bank is higher than that of the solar panel. Since electricity flows from high voltage to low voltage, without a charge controller the electricity would flow out of the battery bank. A charge controller prevents that from happening and allows the flow to only go one way into the batteries. A boost regulator provides an output voltage greater than the input voltage (depending upon switching frequency of switch) hence the name "Boost Regulator". A boost regulator using a power MOSFET is shown in figure 1

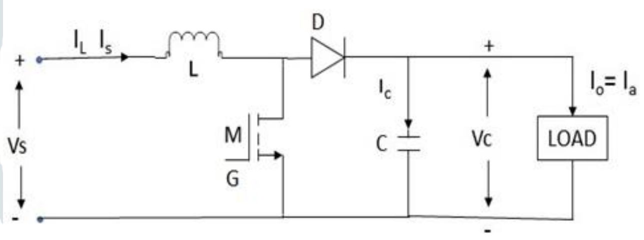

Figure 1. Circuit Diagram of Boost Converter

The circuit operation can be divided into two modes. Mode 1 begins when transistor or switch M1 is switched ON at t = 0. The input current, which rises, flows through inductor L and transistor Q1. Mode 2 begins when transistor M1is switched OFF at t = t1. The current that was flowing through L, C, load, and diode Dm. The inductor current falls until transistor M1is turned ON again in the next cycle. The energy stored in inductor L is transferred to the load.

Assuming that inductor current rises linearly from I1 toI2 in time t2

$$\mathrm{Vs} = \mathrm{L}\frac{\mathrm{I2} - \mathrm{I1}}{\mathrm{t1}} = \mathrm{L}\frac{\Delta \mathrm{I}}{\mathrm{t1}}$$

$$\mathrm{t1} = \frac{\Delta \mathrm{IL}}{\mathrm{Vs}}$$

And the inductor current falls linearly from I2 to I1 in time t2,

$$\mathrm{Vs} - \mathrm{Va} = -\mathrm{L}\frac{\Delta \mathrm{I}}{\mathrm{t2}}$$

$$\mathrm{t2} = \frac{\Delta \mathrm{IL}}{\mathrm{Va} - \mathrm{Vs}}$$

Where $\Delta \mathrm{I} = \mathrm{I2} - \mathrm{I1}$ is the peak to peak ripple current of inductor L [8]

$$\Delta \mathrm{I} = \frac{\mathrm{Vst1}}{\mathrm{L}} = \frac{(\mathrm{Va} - \mathrm{Vs})\mathrm{t2}}{\mathrm{L}}$$

Substituting t1=KT and t2 = (1-K) T yields the average output voltage,

$$\mathrm{Va} = \mathrm{Vs}\frac{\mathrm{T}}{\mathrm{t2}} = \frac{\mathrm{Vs}}{1-\mathrm{K}}$$

which gives,

$$(1-\mathrm{K}) = \frac{\mathrm{Vs}}{\mathrm{Va}}$$

Substituting K=t1/ T=t1finto above equation yields [9]

$$\mathrm{t1} = \frac{\mathrm{Va}-\mathrm{Vs}}{\mathrm{Vaf}}$$

Assuming lossless circuit $\mathrm{VsIs} = \mathrm{VaIa} = \mathrm{VsIa}(1-\mathrm{K})$ and the average input current is

$$\mathrm{Is} = \frac{\mathrm{Ia}}{\mathrm{I}-\mathrm{K}}$$

The switching period T can be found from

$$\mathrm{T} = \frac{1}{\mathrm{f}} = \mathrm{t1}+\mathrm{t2} = \frac{\Delta\mathrm{IL}}{\mathrm{Vs}} + \frac{\Delta\mathrm{IL}}{\mathrm{Va}-\mathrm{Vs}} = \frac{\Delta\mathrm{ILVa}}{\mathrm{Vs}(\mathrm{Va}-\mathrm{Vs})}$$

And this gives the peak to peak ripple current:

$$\Delta\mathrm{I} = \frac{\mathrm{Vs}(\mathrm{Va}-\mathrm{Vs})}{\mathrm{fLVa}}$$

$$\Delta I = \frac{VsK}{fL}$$

When the transistor is on, the capacitor supplies the load current for t=t1. The average capacitor current during time t1 is $I_c=I_a$and the peak to peak ripple voltage of the capacitor is

$$\Delta Vc = Vc - Vc(t=0) = \frac{1}{C}\int_0^{t1} Icdt = \frac{1}{C}\int_0^{t1} Ia = \frac{Iat1}{C}$$

Substituting $t_1 = (V_a - V_s / V_a f)$, We get

$$\Delta Vc = \frac{Ia(Va-Vs)}{VafC}$$

Or

$$\Delta Vc = \frac{IaK}{fC}$$

Condition for continuous inductor current and capacitor voltage:

If IL is average inductor current, the inductor ripple current $\Delta I = 2IL$

$$\frac{KVs}{fL} = 2I_L = 2I_a = \frac{2V_S}{(1-K)R}$$

Thisgives the critical value of inductor L_c as

$$L_c = L = \frac{K(1-K)R}{2f}$$

If V_c is the average capacitor voltage, the capacitor ripple voltage$\Delta Vc = 2Va$ [9]

$$\frac{I_aK}{Cf} = 2V_a = 2I_aR$$

This gives the critical value of the capacitor Cc as

$$C_c = C = \frac{k}{2fR}$$

A boost regulator can step up the output voltage without a transformer. Due to a single transistor, it has a high efficiency. The input current is continuous. However, a high peak current has to flow through the power transistor. The output voltage is very sensitive to changes in duty cycle k and it might be difficult to stabilize the regulator [10][11]. The average output current is less than the average inductor current by a factor of (1-k), and a much higher RMS current would flow through the filter capacitor, resulting in the use of a larger filter capacitor and a larger inductor than those of a buck regulator [12]. The above mentioned boost converter is simulated using MATLAB Simulink 2013 as shown in figure 2. The values of different components of boost converters used in solar pumping system is shown in table I

Table I. Ratings of Proposed Boost Converter

Sr. No	Component	Rating
1.	Inductor (L)	150µH
2.	Capacitor (C)	220µF
3.	Input Voltage (V_i)	15 V
4.	Resistor (R)	40 Ω

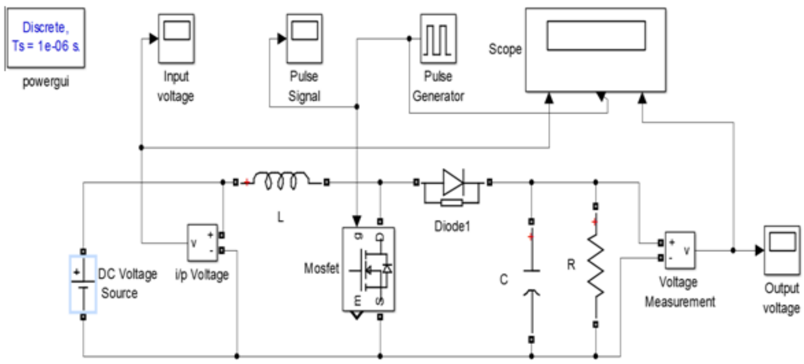

Figure 2. Constant DC Voltage Source Boost Regulator

Figure 3 shows the pulses provided to boost converter, input voltage and constant output DC voltage obtained. It is noted that even though the input voltage is constant, boost converter takes initial time to provide constant voltage

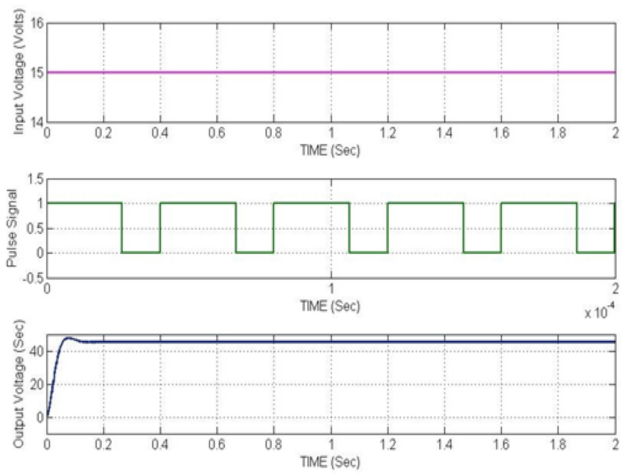

Figure 3. Summarized waveforms for the Constant voltage input of Boost-Converter

The above analysis is done when the input to the boost converter is constant DC where it is noted that initially boost converter take some time around 0.1 second to give constant output power. But the main contribution of this paper that the proposed methodology gives constant output even when the input voltage is varying. The details analysis for varying voltage is shown below. The above analysis mentioned is for open loop whereas the analysis of closed loop is shown below

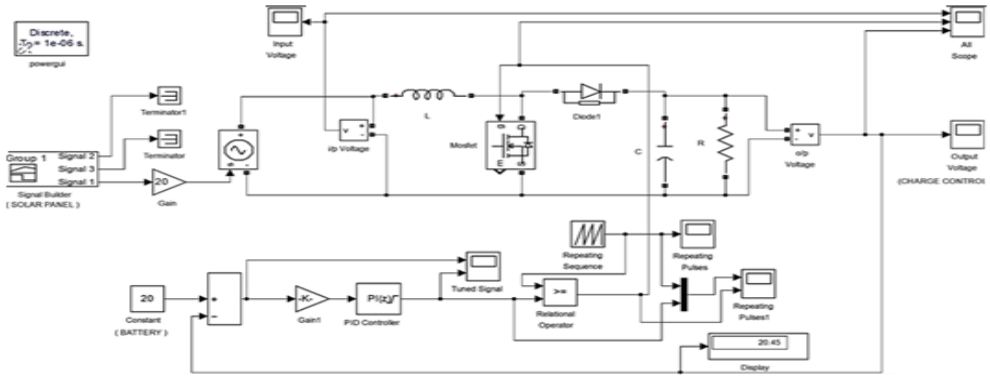

Figure 4. Closed loop circuit and for variable input signal of Boost-Converter

In Boost Converter whenever the supply is given at input, the boost Converter works in two modes. In Mode 1 When the MOSFET Switch is closed the Current I_L flows through the Inductor which charges the inductor with positive polarity. At this time the output voltage is zero. In mode 2 when the MOSFET switch is open the inductor discharges with negative polarity and the current flows through inductor l i.e. i_l and then through diode d i.e. i_d thus the output voltage obtained across the boost converter is Vo = V_l + Vs. In the above analysis, capacitor C is used to regulate the output voltage Vo.

III. CLOSED LOOP BOOST REGULATOR WITH VARIABLE INPUT

The availability of solar-energy on the earth is in tremendous amount. But due to the variations in the intensity of solar radiation, it creates the problem to extract solar-energy at a constant level. Thus, due to the change in radiation the output obtained at the solar panel is also variable in nature [13] [14]. For simulation of constantly changing voltage at a solar panel or solar array terminal, we have used the variable magnitude step inputs to the boost converter. This input signal is created with the use of signal builder followed with controlled voltage source. The simulation for the same values of components of boost-converter with the variable input voltage has been carried out and the results obtained were as follows:

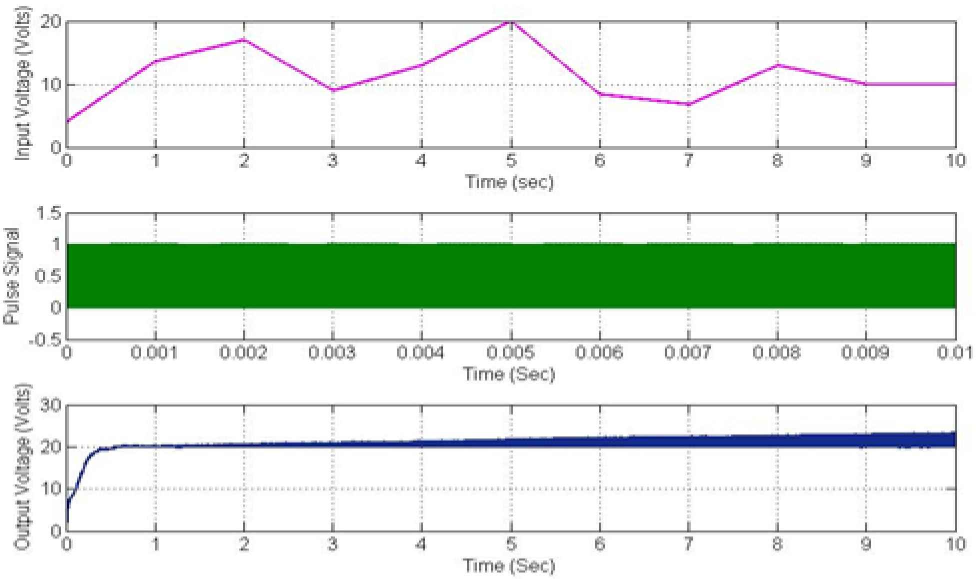

Figure 5. Summarized waveforms for the variable voltage input of closed loop Boost-Converter

IV. RESULTS AND DISCUSSION

Based on the above proposed scheme hardware prototype has been developed for study purpose. The hardware setup consists of mainly four components: Solar panel, Charge Controller (based on PWM technique), Battery and a DC water pump. The main purpose of battery is to provide reference voltage to charge controller in order to obtain a constant DC output power from the entire system. The hardware setup for the proposed scheme is shown in figure.6.

Figure 6. Actual hardware prototype module of proposed scheme

Hardware results of the proposed prototype developed is shown in table II and figure.7. Here it is noted that the output voltage remains constant even though the input voltage to the charge controller is varying with respect to time. The results obtained were acquired on 11/03/2019 at Nagpur city (21.1458° N, 79.0882° E) Maharashtra, India.

Table II. Input-Output Voltage of Boost Converter at different Time Interval

Sr. No	Time	Input Voltage (V)	Output Voltage (V)
1	8:00	15.4	20.1
2	9:00	16.2	20.4
3	10:00	17.7	20.5
4	11:00	19.3	21.5
5	12:00	21.5	21.8
6	13:00	21.8	21.8
7	14:00	21.4	21.8
8	15:00	21	21.4
9	16:00	20.7	21.1
10	17:00	20	20.1
11	18:00	17.8	20.1

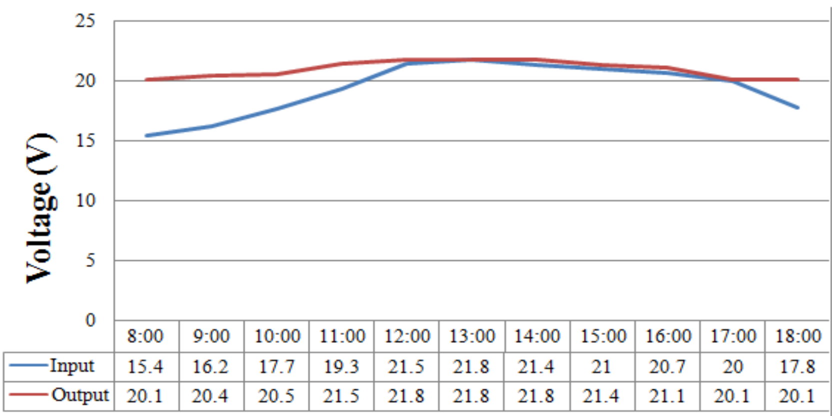

Figure 7. Input-Output Voltage of Boost Converter at different Time Interval

IV. CONCLUSION

A direct driven solar water pumping system with PWM technique is modeled and the performance is analyzed through simulation studies and hardware validation. This paper proposes the performance of designed solar charge controller which is analyzed in both open loop and closed loop mode with constant and variable input voltages. Here it is noted that the output voltage of the proposed system which is implemented on hardware prototype is around 21 Volts throughout the day. Acquired results show that the proposed system performs acceptably well under variable irradiation level and this system can replace the old traditional water pumping system.

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