Design & Simulation of Solar DC Pump in Simulink

P.Badari Narayana
Director, Green Life Energy Solutions LLP,
Secunderabad, A.P, India
E-mail:badari.p@gmail.com

B.R. Sanjeeva Reddy
Research Scholar, NIT Warangal, A.P, India
Email: sanjeev.reddy@nitw.ac.in

Prasad Motepalli
Final B.Tech-ECE, BVRIT,
Narsapur, Medak (Dist), A.P, India
Email: prasu.459@gmail.com

Sanjay Dubey
Professor, ECE-Department,
BVRIT,
Narsapur, Medak (Dist), A.P, India
E-mail: sanjay.dubey@bvrit.ac.in

Abstract— **Solar DC pump system is easy to install and operates full automatically without watching. Solar DC pump needs less solar panels to run than the AC pump. A simulation model is necessary for the manufacturer to assess the performance of solar pump controller. Solar DC Pump consists of solar PV Modules, solar DC controller, and submersible DC pump. Solar cells have nonlinear I-V characteristics, efficiency of PV module is low and output power depends on solar isolation Level and ambient temperature. Main point to consider, there will be great loss of power due to mismatch of source and load. So to extract the maximum power to load from PV panel MPPT is implemented in the boost converter circuit using PWM and Microcontroller. The proposed design optimizes the solar power System to deliver the maximum power to load from source and is presented in the developed Simulink model. This model acts as a template for designing Solar DC pump of required rated capacity. In this work, Parameter extraction, Model evaluation, design & analysis of PV panel characteristics, modeling boost converter and DC pump motor are demonstrated using MATLAB/Simulink model.**

Keywords: Solar Photovoltaic module, Boost converter, MPPT algorithm, PWM, Microcontroller, Buck converter, DC pump

I. INTRODUCTION

Renewable energy especially solar photovoltaic is important alternative source of energy for the future, and research and development done on this area attained importance in using solar cells to power the electrical systems. The two inherent problems in solar technology is low conversion efficiency (10%to 16% efficiency for commercially available amorphous silicon solar cells) and next one is the presence of highly non-linear I-V characteristics. The problem gets worse due to dependence of characteristics of solar cell on temperature and insolation level. Further, due to mismatch between the operating point and maximum power point (MPP) of the solar cells, the power available. From the solar cell is not fully extracted. In order to extract the maximum power from the source PV panel must be capable of tracking the solar panel unique maximum power point that varies with irradiance and temperature. MPPT is implemented by using any one of the algorithms perturb & observe (P&O), incremental conductance. This is represented in the current simulink environment through a PWM generator that has the same value of duty cycle [1] [2].

I-V characteristics of solar cell play an important role in designing a solar powered device. The two major parameters of solar cell are V_{oc} (Open circuit voltage) and I_{sc} (short circuit current). Current from the solar cell is calculated by the characteristic equation of solar cell which involves I_{sc}, V_{oc}, R_s (series resistance) and Temperature. For the present design exercise, modules such as boost converter, buck converter, DC motor are modeled in Simulink.

II. DESIGN CALCULATIONS OF SOLAR PUMP

A simple model is chosen for the MATLAB modeling and simulation. A simple PV cell is represented by a light dependent current source (I_{sc}) in antiparallel with a diode driven by current I_d[2] and a series resistance in the current path through semiconductor material, the metal grid, contacts and current collecting bus [4]&[5].

A simple power calculation is given below for designing a solar DC Pump for a required capacity.

Step 1: Amount of water required per day is 25,000 liters/day.
Step 2: Total Dynamic Head (TDH). It depends on two factors.

- Total Vertical Lift.
- Total frictional losses.

TDH= Vertical lift + Frictional losses.
Vertical lift = Elevation+ standing water level+ Draw down.
Frictional losses = 0.5% of Total vertical lift for the given specifications,
Vertical lift= 16 m.
Frictional losses= 16*0.05/100= 0.008m
Then TDH=16 m+0.008 m =16.008m.

Step 3: Hydraulic energy required to raise the water level per day is…
= Mass* g*TDH.
= (Density*volume)*g*TDH.

= $(1000kg/m^3*25m^3/day)*9.8m/s^2*16.008m$.
= 1089.43 watt-hour/day.

Step 4: Solar radiation data = 6hours/day. (Peak =1000watt/m^2).

Step 5: Size and number of solar PV modules required are…

Total wattage of PV panel = Total hydraulic energy/no. of hours.

= 1089.43/6 =181.57 watt.

System losses = Total PV panel wattage/ (pump efficiency * mismatch factor).

=181.57 watt/ (0.3*0.85) = 712.03

Considering operating factor = Total PV panel wattage after losses/operating factor.

PV panel capacity = 712.03/0.75 =949.38watt.

Number of PV panels required = 949.38/240 ~ 4.

1 HP DC motor can be run with a solar capacity of 960Wp with the available 240Wp model solar panel.

III. MODELLING AND VALIDFATION IN SIMULINK

Solar Panels, Boost converter, DC pump are separately modeled and unified in Multisim and simulink environments as shown below.

A. Simulation of Solar Panel

A simple modeling is chosen for MATLAB modeling and simulation. A simple PV cell is represented by a light dependent current source (Isc) in antiparallel with a diode driven by current I_d[2] and a series resistance in the current path through semiconductor material, the metal grid, contacts and current collecting bus [4]&[5]. The presence of diode determines the output V-I characteristics of solar cell.

The parallel resistance associated with a small leakage of current through a resistive path in parallel with an intrinsic device [5] & [6] is very large, so its effect is very less and is neglected. The equations which govern the characteristics of solar cell are:

$$I = Isc - Io\left[e^{q(V+IRs)/nKT} - 1\right] \quad (1)$$

$$Isc|_G = \left(\frac{G}{Go}\right) Isc|_{Go} \quad (2)$$

$$Io|_T = Isc|_{Tref}\left(\frac{T}{Tref}\right)^{3/n} e^{-\left(\frac{qEg}{nK}\right)\left(\frac{1}{T}-\frac{1}{Tref}\right)} \quad (3)$$

$$Isc|_T = Isc|_{Tref}\left[1 + a(T - Tref)\right] \quad (4)$$

$$I = Isc - Io\left[e^{q(V+IRs)/nKT} - 1\right] - \frac{V + IRs}{Rp} \quad (5)$$

$$Rs = -\left(\frac{dV}{dI}\right) - \frac{nKT/q}{Io\left[e^{q(V+IRs)/nKT} - 1\right]} \quad (6)$$

Solar cell now is a direct element of simelectronics library part of MATLAB 2012's simulink environment.

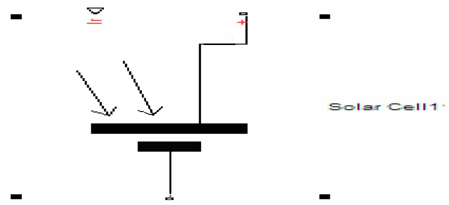

Figure 1: Equivalent circuit for solar cell in MATLAB simulation

The two important curves which provide the complete information about solar cell are I-V curve and P-V curve which are drawn for the rated solar panel available in the industry (240Wp).

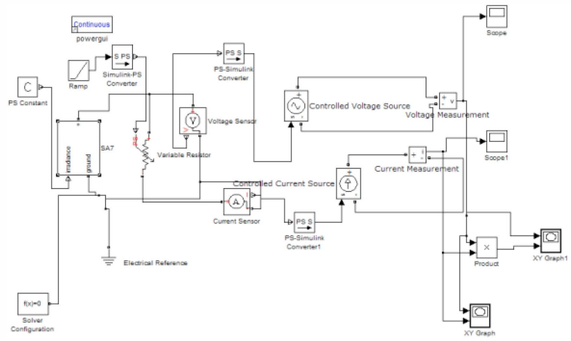

Fig 2. Simulink model for Solar Panel

The values of the power curves generated in simulink are in agreement with the selected solar panel of 240Wp [9].

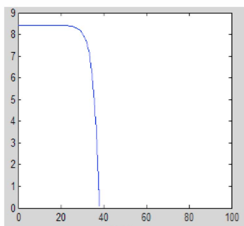

Fig 3.I-V curve

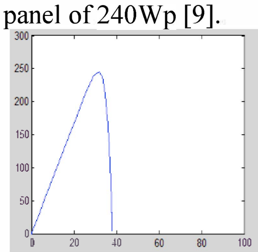

Fig 4.P-V curve.

PV module designed using solar cells connected in series and the parameters choosen for solar cell are given below.

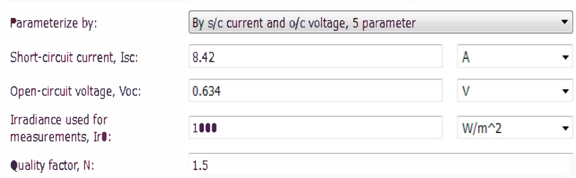

Fig 5.parameters

Amount of irriadiation = 1000 watt/m^2.

Short circuit current (I_{sc})=8.42 amp

Open circuit voltage(V_{oc})=38V.

Quality factor(N)= 1.5.

Series resistance=0.001 Ω.

B. Simulation of Boost converter in Multisim environment

Boost converter is an Electronic DC to Dc converter which allows us to implement the MPPT algorithm by varying the duty cycle of PWM which is given to IGBT, PWM is generated by Microcontroller, through MPPT algorithm implemented in microcontroller.

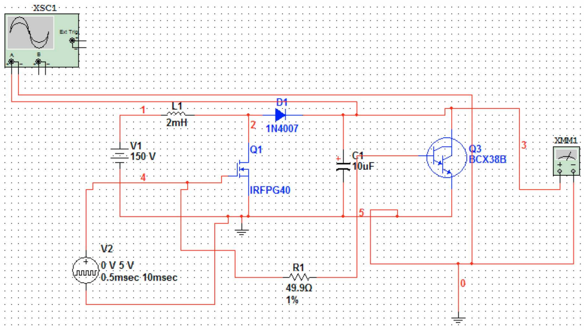

Fig 6. Boost converter.

C. Simulink model for DC pump.

Here, DC motor of 1 HP is run by PV array through boost converter circuit to extract the maximum power from the source. The simulated model for DC motor is presented below.

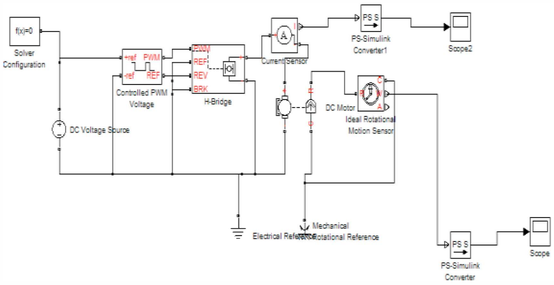

Fig 7. DC motor model

D. Simulink model for Solar DC Pump

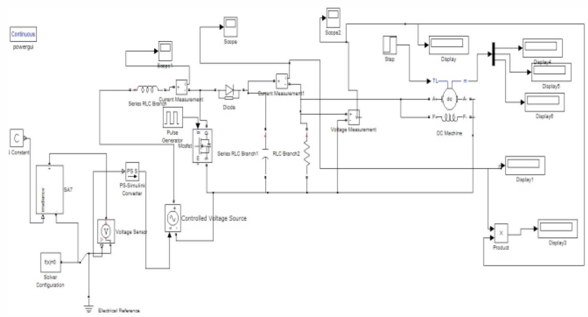

Fig 8. Solar DC Pump model in simulink

Solar module designed by solar cells is connected to DC motor through Boost converter circuit that has MPPT algorithm [7]. The modeled Solar DC pump displays the designed speed and voltage specifications.

IV. Conclusions

Solar DC pumps are gaining popularity as they are easy to install for rural agricultural applications. Solar DC Pump is an integral product of Solar PV Panels, Controller and Submersible DC pump. Solar panels with effects of variations in temperature, insolation power output are observed and analyzed for MPPT design. The modeling of each component of PV system simulated in MATLAB gives the feasibility of the system under real weather conditions. Solar pump model using the equivalent circuit of moderate complexity was chosen for simulation and found to be in good matching with the available solar DC pump in the market.

The designed simulink module can be used as a template to design solar DC powered water pumping system of required capacity. This current exercise of simulation of solar DC pump is very helpful to the solar pump manufacturer for optimizing the design of solar DC pump controller.

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