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SOLAR CHARGE CONTROLLER FOR DOMESTIC APPLICATION

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Abstract— In this paper, a solar charge controller with Maximum Power Point Tracking is designed and implemented using Matlab Simulink. There is also an output inverter integrated with the system to obtain a single phase AC output to power the home appliances. For the maximum power point tracking two methods, the Perturb and Observe (P&O) and Incremental Conductance (INC) algorithms are implemented and their performance is analysed. With the changing irradiance, the MPP is tracked effectively and a regulated DC voltage is obtained using Buck-Boost converter, which is suitable for the selected pulse width modulation (PWM) inverter. Mathematical modelling of the same is performed, establishing the relation between various mathematical equations and estimating quantitative behavior of the physical system.

Keywords— Solar Photovoltaic (PV) System, MPPT, P&O Algorithm, INC Algorithm, DC-DC Buck Boost Converter, PWM inverter, Charge Controller

I. INTRODUCTION

Developing countries like India rely on conventional sources for their energy demand. In recent days it can be seen that the prices of these sources are increasing rapidly. This could cause energy scarcity and deteriorate the lifestyle of its citizens. Due to these reasons we need to switch to much cheaper and efficient sources of energy. There are many sources of non conventional energy sources and one of them being solar energy which is free of cost and abundantly available. This can be harnessed easily with the help of solar panels and few protection devices.

This source has numerous advantages. It can either be used on grid or off-grid. The remote places like villages or places with less grid connectivity can be off grid. The places with good grid

connectivity can use this as an on-grid system and supply the excess energy generated to the grid.

The paper gives an overview about a solar charge controller which comprises a solar panel, MPPT algorithm, Buck-Boost converter and inverter.

The looms solar 180W panel has been considered here for experimentation. Here two types of MPPT algorithms are used. One being P&O [1] and other being the INC algorithm, while there are various algorithms available [2]. The buck-boost converter with a closed loop control provides a constant DC voltage to the inverter to obtain a single phase AC voltage. The inverter uses PWM technique. MPPT solar charge controllers are more effective and widely used than PWM controllers [3][6]. The functional blocks of the system will be explained in further sections.

II. SYSTEM DESIGN

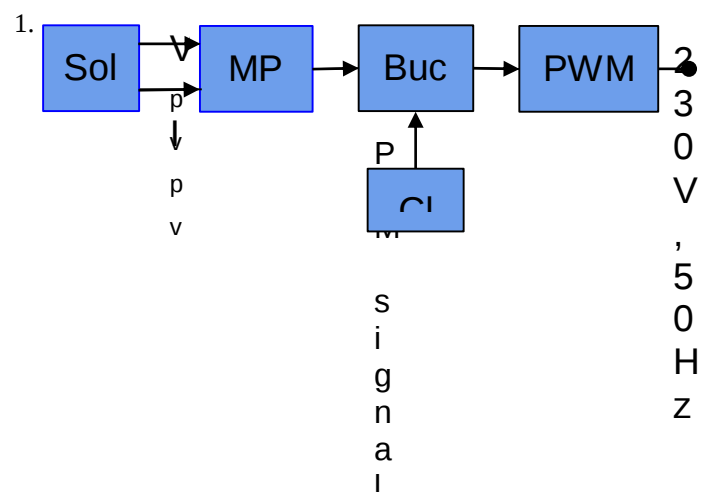


Fig. 1. Block diagram of the MPPT charge controller

A. Solar Panel

A photovoltaic cell is a semiconductor device made up of crystalline silicon that converts solar energy into electrical energy by the principle of photovoltaic effect. Such solar cells are arranged in series and/or parallel in order to meet the required voltage and current requirements and form the PV module. The below table lists the electrical specifications of the solar panel measured at Standard Test Conditions (STC) i.e. 1000W/m² irradiance and 25°C temperature.

Table - 1 PV panel electrical parameters at STC

Parameters	Rating
Cell Configuration(Nos)	36
Maximum Power(P _{max})	180 W
Voltage at Maximum at PowerPoint(V _m)	19.95 V
Current at maximum powerpoint(I _m)	9.03 A
Open circuit voltage(V _{oc})	23.26 V
Short circuit current(I _{sc})	9.53 A

The simulink model of the panel was designed with help of the above shown parameters [7]. The design equations used for mathematical model [8][9] are given below:

1) Module photo-current I_{ph}:

$$I_{ph} = [I_{sc} + K_i(T - 298)] \times I_r / 1000 \quad (1)$$

Where, I_{sc} = short circuit current

K_i = Short circuit current of the cell at 25°C, 1000 W/m²

T = operating Temperature

I_r = solar irradiation

2) Module reverse saturation current I_{rs}:

$$I_{rs} = I_{sc} / [e^{(q.V_{oc}/N_s.k.N.T)} - 1] \quad (2)$$

Where, q = electron charge = 1.6 x 10⁻¹⁹ C

V_{oc} = open circuit voltage

N_s = no. of cells connected in series

3) Module saturation current I_o:

$$I_o = I_{rs} [T/Tr]^{-3} e^{[q \times E_{go}/nk(1/T - 1/Tr)]} \quad (3)$$

Where, Tr = Nominal Temperature

E_{go} = band gap energy of semiconductor = 1.1 eV

n = ideality factor

k = Boltzmann Constant = 1.38 x 10⁻²³ J/K

4) The current output of PV module:

The output current of the panel is given by the equation,

$$I = N_p \times I_{ph} - N_p \times I_o \times [e^{(V/N_s + I \times R_s/N_p)/n.V_t} - 1] - I_{sh} \quad (4)$$

$$V_t = k \times T/q \quad (5)$$

$$I_{sh} = (V \times N_p/N_s + I \times R_s)/R_{sh} \quad (6)$$

Where, V_t = Diode terminal voltage

N_p = No. of PV Modules connected in parallel

The output of the solar panel is fed to the MPPT controller.

1. B. MPPT Controller -

MPPT controller is used to track and maintain the operating point near the maximum power point. The maximum power varies with solar radiation, cell temperature and ambient temperature. The MPPT algorithm is implemented using a Boost Converter whose circuit components are designed using the following equations. This logic can be implemented using a microcontroller in hardware projects [4][5].

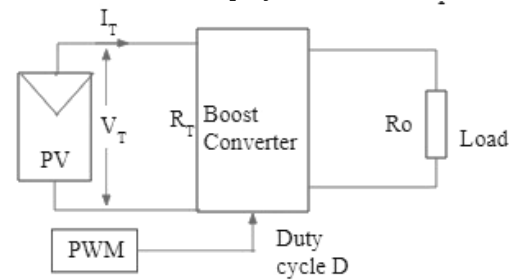


Fig. 2. MPPT with boost converter

For 1000W/m², the panel voltage and current are V_T = 19.95V, I_T = 9.03A respectively. R_T = 2.2093Ω. Let load resistor R_o = 10Ω, switching frequency f_{sw} = 50KHz

For the Boost converter,

$$R_o = R_T / (1-D)^2 \quad (7)$$

Therefore, D = 0.5299

Boost converter output voltage is given by,

$$V_o = V_T / (1-D) \quad (8)$$

Hence, V_o = 42.437V

Current through the inductor is given by,

$$I_L = V_T / (1-D)^2 R \quad (9)$$

Hence, I_L = 9.0274A

Considering the ripple in output voltage and inductor current to be 0.1%,

$$\Delta I_L = 0.1\% \times I_L \quad (10)$$

Hence ΔI_L = 9.0274mA

Inductor of the Boost converter is given by,

$$L = V_T D T_s / \Delta I_L \quad (11)$$

Hence, L = 23.42mH

Capacitor of the converter is given by,

$$C = DT_s / R(\Delta V_o / V_o) \quad (12)$$

Hence, obtain, $C = 10.6\text{mF}$.

The MPPT algorithms that are employed are Perturbation and Observation (P&O) and Incremental Conductance (INC) techniques. The flowchart of these algorithms are shown below in Fig. 3 and Fig. 4 respectively.

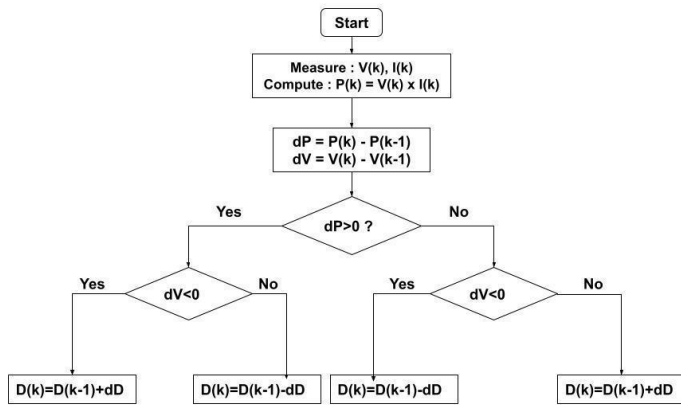


Fig. 3. Flowchart P & O Algorithm

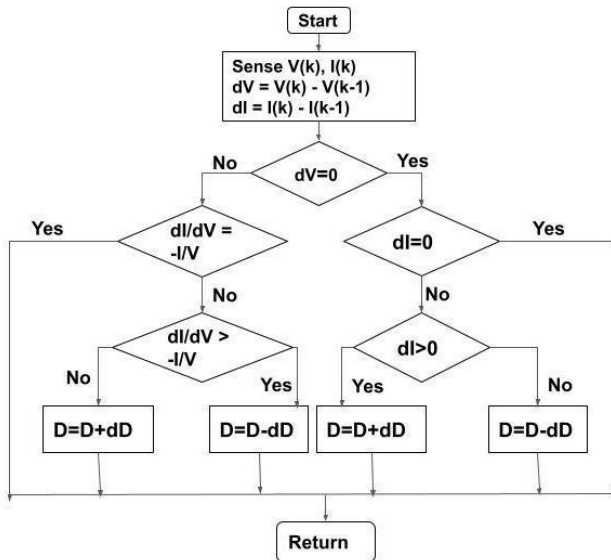


Fig. 4. Flowchart INC Algorithm.

C. DC-DC Converter -

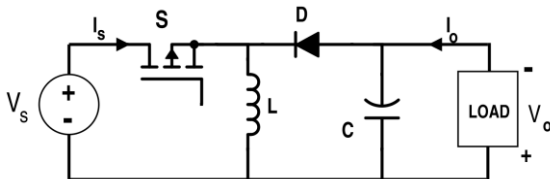


Fig. 5. Buck-Boost converter

The buck boost converter acts as both buck and boost converters depending on duty ratio . It acts as a buck from duty ratio of 0 to 0.5 and acts as a boost converter from 0.5 to 1. The output of the converter is inverted by 90° . A closed loop control [10] is implemented in order to keep the output constant with varying input. The design calculations of the buck-boost converter are as follows:

Let the switching frequency be $f_{sw} = 100 \text{ kHz}$, load resistor $R_{o,min} = 1\Omega$, percentage ripple of output voltage be 0.01% For the minimum output voltage from MPPT i.e. $V_{in,min} = 10\text{V}$, $V_o = 12.6\text{V}$

The output to input ratio of buck-boost converter is,

$$V_o/V_{in} = D/(1-D) \quad (13)$$

Therefore, $D_{V_{in}=10\text{V}} = 12.6/(12.6+10) = 0.5575$

To calculate the value of the inductor, we use,

$$L = 1.25 L_{min} \quad (14)$$

$$L_{min} = (1-D)^2 R / 2f \quad (15)$$

$$L_{min} = (1-0.5575)^2 \cdot 10 / 2 \cdot 10^5 = 9.7903\mu\text{H}$$

$$\text{Therefore, } L = 1.25 \cdot 9.7903\mu\text{H} = 14.685\mu\text{H}$$

The capacitor value is given by,

$$C = V_{in} \cdot D^2 \cdot T_s / (\Delta V_o \cdot (1-D) \cdot R_o) \quad (16)$$

Hence we get $C = 55.8\text{mF}$

For the maximum output voltage from MPPT i.e. $V_{in,max} = 42\text{V}$, $V_o = 12.6\text{V}$ all the above values were similarly calculated and can be summarized as given below:

$$C = 55.8\text{mF}, L = 36.98\mu\text{H}.$$

D. PWM Converter -

The DC output from the buck boost converter has to be converted to AC for outlets. Hence PWM inverter [11][12] is being used. This makes use of triangular waves as carrier signals and sine waves as modulating signals.

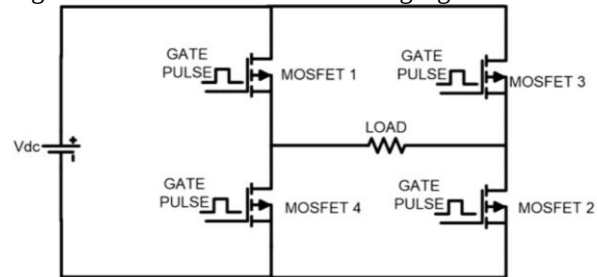


Fig. 6. PWM inverter with H-bridge topology

The design is as given below :

The Fourier series of the output voltage is given by,

$$V_o(t) = \sum 4V_s/n \sin(n\pi/2) \sin(n\pi t) \quad (17)$$

Here, π is the pulse width/pulse angle i.e. duration of ON pulse for one half cycle [Since the V_o is symmetrical along x-axis, even harmonics are absent]. To find out the rms value of the fundamental component consider $n=1$

$$V_o = 4V_s/\pi \sin(\pi/2) \quad (18)$$

By substituting $V_s = 12.6V$ and $\pi = 143.235^\circ$ in equation 18, we get
 $V_o = 15.224V$.

III. SIMULINK CIRCUIT MODEL AND RESULTS

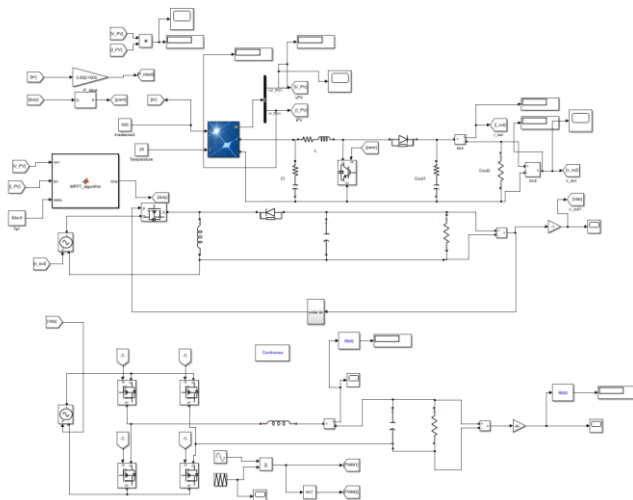


Fig. 7. The overall simulation diagram of Solar charge controller using P&O technique

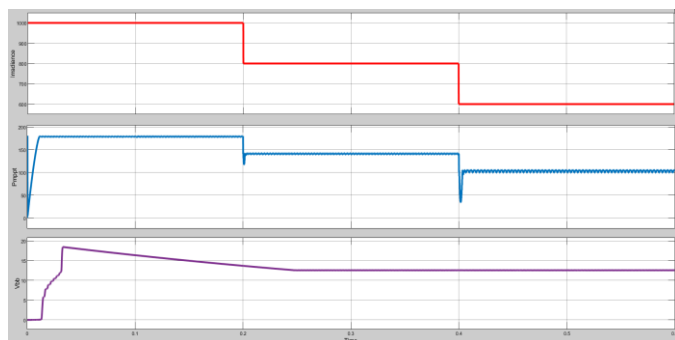


Fig. 8. Variation of MPPT power and dc output of buck-boost converter with the change in irradiance

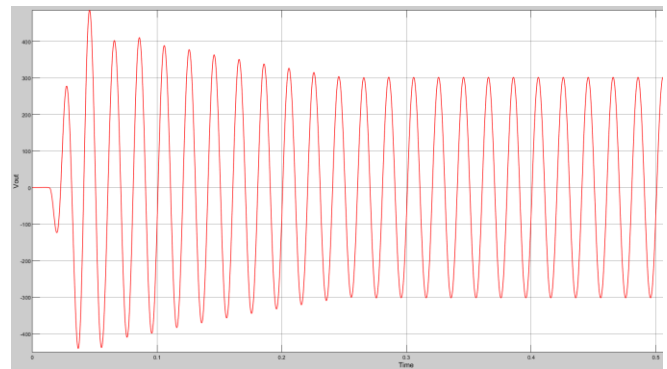


Fig. 9. The output voltage waveform of the combined circuit

Figure 7 shows the circuit model of the MPPT charge controller connected to the PV panel. The MPPT algorithm is coded in the Matlab Function block and with the changing irradiation (temperature being $25^\circ C$), the maximum power from the PV panel also changed. The red line in the waveforms of figure 8 indicates $1000W/m^2$, $800W/m^2$ and $600W/m^2$. The output power of the MPPT controller was found to be 178.01W, 142.3W and 105.1W for the above irradiances (as shown by the blue waveforms). The purple waveform indicates the constant dc voltage of around 12.6V given by the Buck-Boost converter irrespective of the changing irradiances.

The sinusoidal waves in figure 9 indicate the output voltage of the combined system at $1000W/m^2$ and the RMS value of the signal is 230 V. An R-L load of $R=240\Omega$, $L=0.5mH$ is used.

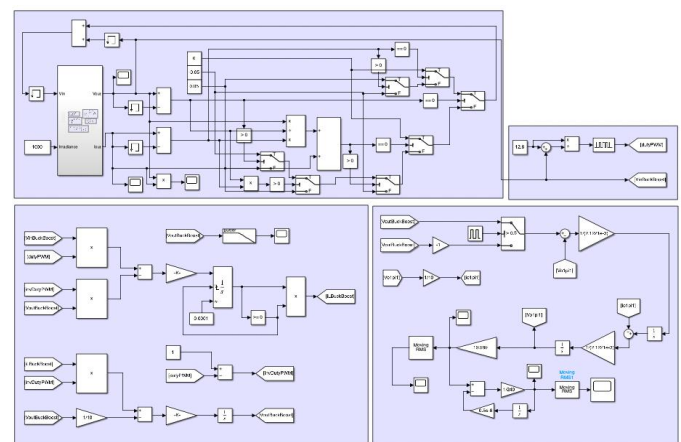


Fig. 10. Mathematical model of the charge controller with INC MPPT algorithm and RL load

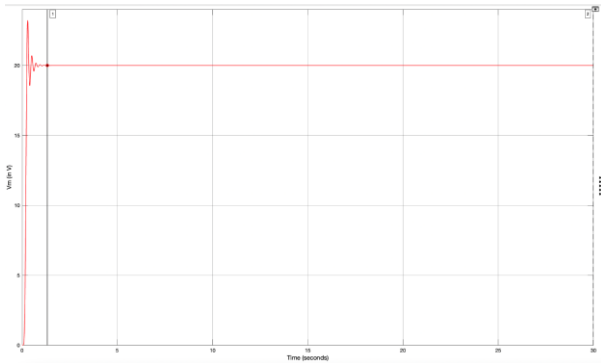


Fig. 11. (a) Voltage from P&O MPPT Controller at 1000W/m^2 , 25°C RL load

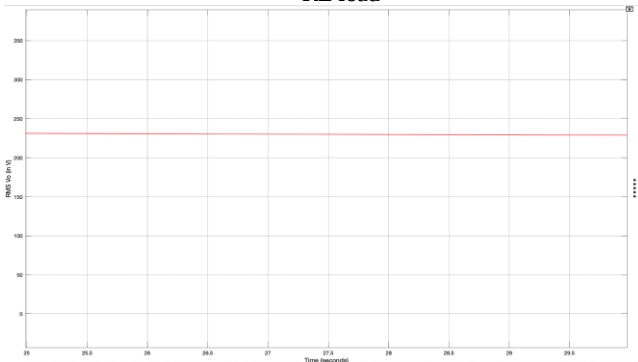


Fig. 11. (b) Voltage from INC MPPT controller at 1000W/m^2 , 25°C and RL load

In figure 11, although the voltage value is at 19.95V in both graphs, graph (a) i.e. The P & O algorithm has a starting ripple and takes a few seconds to attain the steady state value. Hence the advantages of INC algorithm over P&O are:

- 1) Starting ripple in voltage and current waveforms is reduced in INC
- 2) The voltage increment after comparison with the previous values happens significantly faster in this algorithm and hence the operating point at MPP can be attained quickly.

Table - 2 Outputs of two different loads for different irradiation from Mathematical model

Solar irradiation	R load	R-L load
Output at 1000W/m^2	230V (RMS)	230.05V, 0.958 A (RMS)
Output at 800W/m^2	230V (RMS)	230V, 0.9588A (RMS)
Output at 600W/m^2	230V (RMS)	230.2V, 0.9583A (RMS)

IV. CONCLUSION

The energy harvesting and solar energy storage model has been successfully implemented using the MPPT charge controller in

order to obtain a single phase 230V, 50Hz AC supply which can be used to power many domestic appliances. A complete robust set-up such as this as a whole is currently unlikely to have been simulated using simulink circuit and mathematical model. The P&O algorithm as well as INC algorithm has been successfully implemented and the integration of the individual working component has resulted in the production of the desired output, within appreciable range.

There are many solar MPPT charge controllers in the market with multi-voltage ranges of about 12V to 24V which can be connected with the batteries and solar panels. But most of them do not have interactive displays or in-built inverters and they have more scope to connect to the internet or remote databases.

V. ACKNOWLEDGMENT

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