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Design and analysis of power electronics interface unit with controller for photovoltaic system

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Abstract

The solar photovoltaic (PV) cell exhibits the current(I)-voltage(V) and power (P) –voltage(V) characteristics it is desirable to always use at maximum power tracking to increase the efficiency of the PV system. In accordance to extract maximum power from the PV panel and maximize the PV system output the research has main aim to develop an algorithm suitable for extract maximum power irrespective changing environmental condition and protection issues such as partial shading fault, hot spot fault, line to line fault, Open circuit fault are protected the system by developing the new algorithm.

The proposed novel algorithms are fast tracking the point of maximum power and protecting the PV system hence the efficiency of the PV system is increased and protected the PV system against various fault.

Keywords—*Maximum power point (MPP), photovoltaic (PV). Graphics User Interface (GUI), Pulse Width Modulation(PWM*)

1. Introduction

The prosperity of country and growth of economic depends on the energy generation and consumption, the increased use of energy in industrial agricultural and domestic sector, hence the energy demand will become more and more by the year 2020 it will have predicted the demand will become triple with respect to present.

The generation from renewable energy consistently increasing last decades and the PV technology is fastest growing source of energy, presently KW for domestic application to MW scale PV [1] - [6].

Recent works reflect the interest of designing of proper controller and extracting maximum power from the module Other methods that have been used to optimizing and enhancing extracting power from PV module such as Fuzzy logic and neural network method and mat lab/GUI interface [7] - [12].

The rest paper is organized as follows. Section 2 Deals with design consideration of boost converter with sensing network and novel optimized P&O algorithm, Section 3 proposes testing of panel and sensors and section 4 deals with implemented hardware, the result discussion and validation is done with developed GUI software are stated in section 5 and conclusion is stated in section 6.

2. Design considerations

The figure 1 shows a step up boost converter. In which the input voltage is stepped up to required magnitude. The converter has the input dc voltage source V_s, Inductor L, Switch S, diode D, filter capacitor C. and load resistance R,

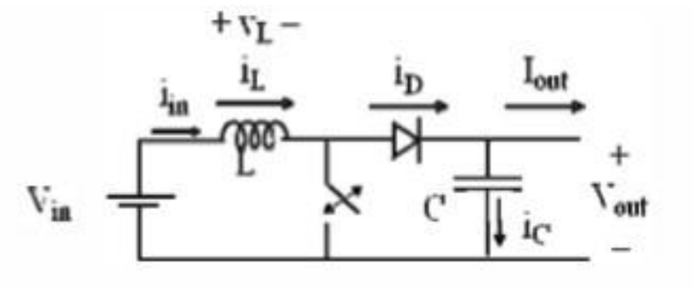

Fig.1 Boost Converter

Design of Inductor (L)

$$L = \frac{D(1-D)^2 R}{2f} \qquad (2)$$

Where,

D = Duty ratio, f =switching frequency and R is load resistance
D=0.5 and R = 29 Ohm and f = 5 KHz
Design of Capacitor (C)

$$C = \frac{D}{R\left(\Delta V_0/V_0\right)f} \quad (3)$$

Where, D=0.5, R = 29 Ohm, f = 5 KHz and $(\Delta V0/V0)$=0.001, The Designed values are: L = 1.4 mH and C = 1200 µF (Electrolytic)

2.1 Design of Sensing networks

The following two sensors are used to get the PV panel voltage and current

a) Voltage Sensor (V_{pv}): The resistive divider network is used to sense input PV panel voltage V_{pv} the resistor value of resister is obtained using following equation

$$V_{R2} = V_{in} \cdot \frac{R_2}{R_1+R_2} \quad (4)$$

Where, V_{in} = Input maximum PV voltage and V_{R2}=Maximum voltage to ADC pin of microcontroller(5V)
Design value of resistors for single PV panel with maximum PV voltage
panel input Voltage Vin = 21V, Let R_1= 1 K Ohm, V_{in} R_2 and V_{R2} in above equation (4) R_1 is calculated, ie, R_2 =312 Ohm
when the PV panel voltage is maximum ie 21Volt, the voltage across R_2 is 5 volts. Design value of resistors for two PV panel connected in series V_{in} = 42 Volt, Let R_1= 10 K Ohm and R_2 =1.3 K

b) Current Sensor (I_{pv}): The resistor having 1Ω of 0.5W rating is used to sense the PV panel current. The voltage drop across the resistor is directly proportional to the current flowing through the resistor

$V = I_{pv} / R$ (5)

Where V= voltage droop across resistor and 'R' Current Sensing resistor.

2.2 PWM generation using 555 timer

The figure 2 shows the Schematic of discrete PWM generation using IC 555.

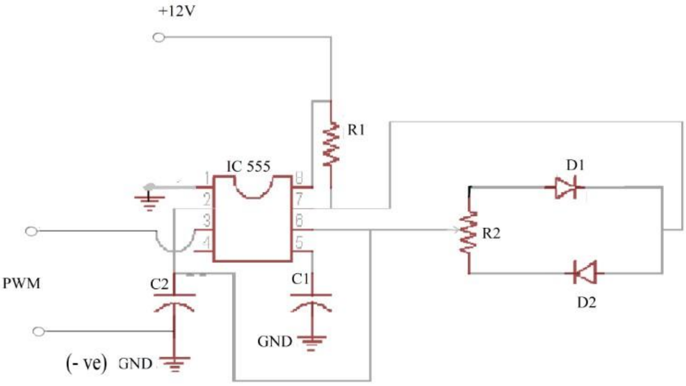

Fig. 2 Schematic of discrete PWM generation using 555 timer.

The output frequency can be calculated from following equation

f=1.44 / (R1+2R2) C (6)

The time period T = T=1/f (7)

T= 0.693(R1+2R2) C (8)

For, 5 KHz the time period is 200 micro second
The following are the designed values of R1, R2 and C R1=1.68, K, R2=1.2K and C= 0.1µF

2.3 Design equation for Dc to Dc converters for GUI software

The following dc to dc converter equation are used to compute duty ratio of the converter.

Buck converter:

Vo = D ×Vin (9)

Where, V_{in} =Input Voltage, V_o = Output Voltage D= Duty ratio of switching device
The reflected input side impedance 'Rin'

$R_{in} = V_{in} / I_{in} = R_L (1/D)^2$ (10)

Boost Dc - Dc converter:
Output voltage 'Vo' given by following equation

$V_o = V_{in} / (1 - D)$ (11)

$R_{in} = R_L (1-D)^2$ (12)

Buck boost DC- DC converter:

$V_o = D / (1-D)$ (13)

$R_{in} = R_L (1-D)^2 / D$ (14)

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2.4 Proposed optimized algorithm

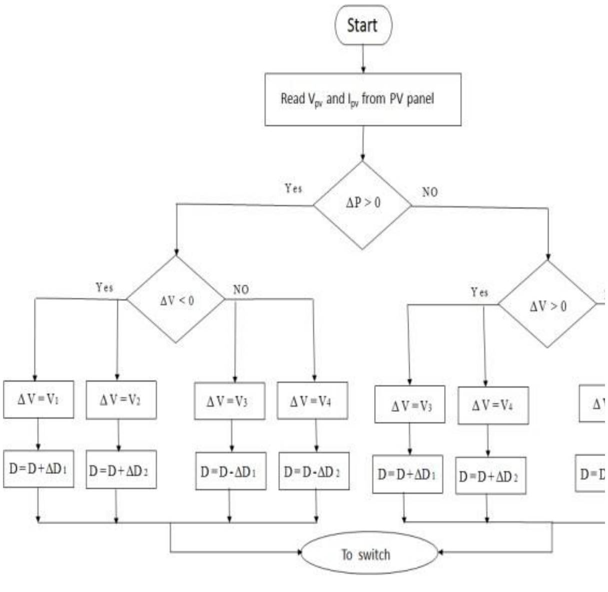

Fig 3. Flow chart of proposed Optimized P & O algorithm

The above fig illustrated the proposed optimized P & O algorithm due to variation in voltage the MPP will change accordingly hence to achieve MPP the duty cycle of converter varied. The variation of PV panel voltage is compared with constant values depending upon amount of change in voltage, the duty ratio of boost converter varied appropriately to achieve the MPP.

2.5 Protection of PV panel and proposed fault detection algorithm for PV panel

The healthy operating condition of PV panel is necessary to obtained or extract maximum power, the PV panel is protected against Partial shading fault, Hot spot fault, Line to line fault, Open circuit fault and Ground fault.

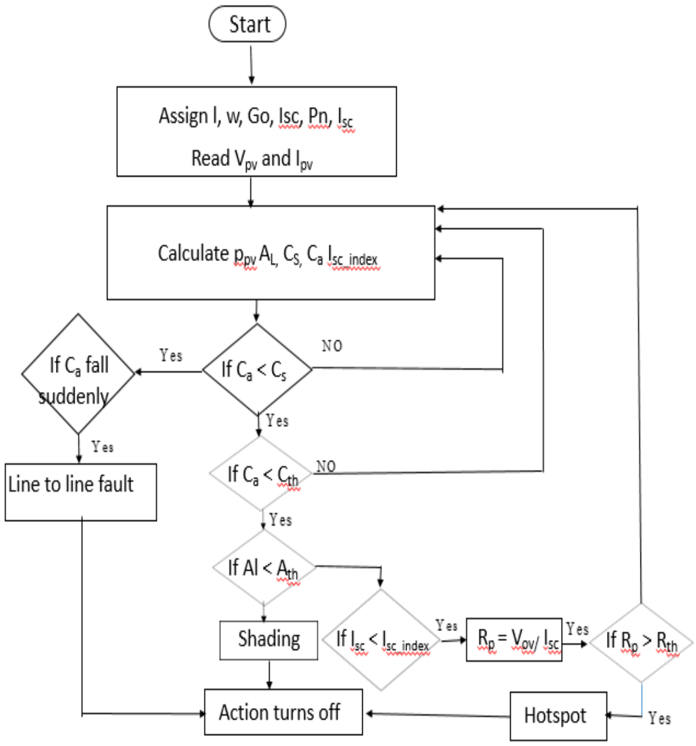

Fig.4 Proposed fault detection algorithm for PV panel

The following constants and equations are used to compute the quantities for necessary action.

Where, W=radiation, G=actual irradiation Go=slandered irradiation $1000w/m^2$, I_{sc_index}= Short circuit current index, P_m=Maximum power, P_{pv}=PV power, P_n = Number of panel , l=length of panel, w=width of panel , A_L= Array loss, C_s=Slandered condition ,C_a=Actual condition, I_{sc}= Short circuit of PV panel, R_{panel} =resistance of the panel, R_{th}= threshold resistance of the panel.

The following equation are used to compute the quantities.

$$G = \frac{Ppv \times Ipv}{length \times width} \quad (15)$$

$$Al = Pm\left[\frac{G}{Go}\right] - Ppv \quad (16)$$

$$Cs = \frac{\text{Mpp ofPV array STC condition}}{Go} \quad (17)$$

$$Ca = \frac{Vpv \times Ipv}{G} \quad (18)$$

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Short circuit current index

$$= \frac{(Isc \times Pn) - Actual\ current\ of\ all\ the\ panel}{Isc \times pn} \quad (19)$$

$$Rpanel = \frac{Voc}{Isc} \quad (20)$$

3.Testing of panel and sensors

3.1 solar panel testing

The Fig.5 shows the Boost converter with PWM. The solar PV panel are tested by using timer PWM circuit to boost converter the tests are carried out for verify the panel details such as V_{oc} and I_{sc} are verified.

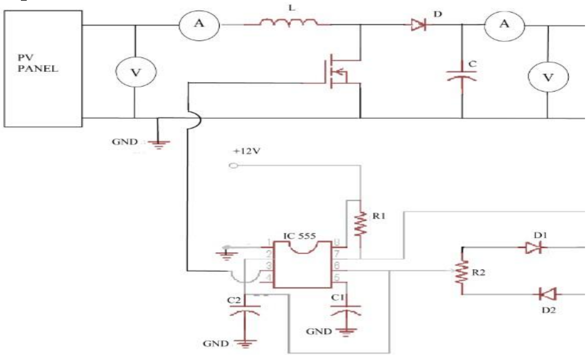

Fig.5 Boost converter with PWM (using 555 timer)

3.2 Testing of Voltage sensor

The figure 6 illustrate the voltage sensor testing through voltage divider network. The sensed PV voltages are given to microcontroller and the serial monitor is used to display these values and other values obtained from digital multimeter, which is connected across voltage sensor resistor both the values results are compared.

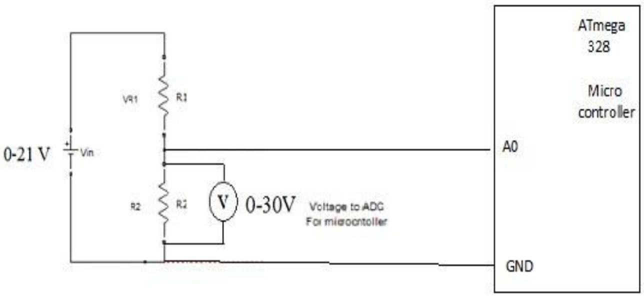

Fig. 6 Schematic of Voltage sensor testing through voltage divider network.

3.3 Testing of current sensor

The figure 7 illustrate the schematic of current sensor testing through resistor. The sensed PV currents are compared with digital multimeter. The current is obtained by measuring voltage drop across low value series resistor.

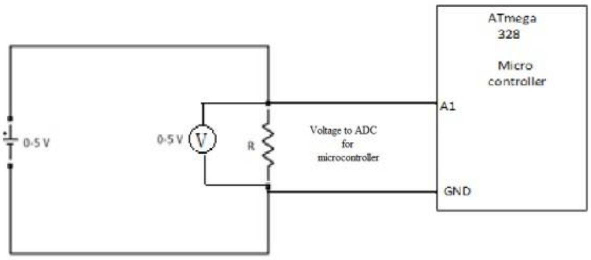

Fig.7 Schematic of current sensor testing through resistor

4. Implemented hardware with optimized algorithm and Interactive Graphic user interface(GUI) based developed software

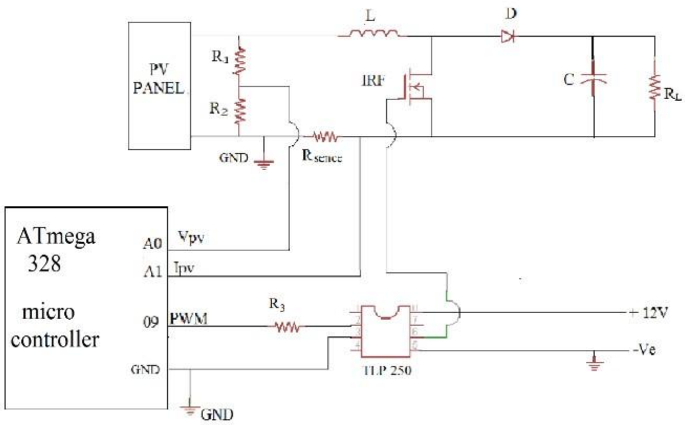

Fig.8 Schematic of implemented hardware with optimized algorithm

The GUI software is developed to validate the obtained hardware implemented result, the developed GUI can compute the duty ration of following three converters with respect to maximum power tracking (MPPT) to vary the input side reflected impedance in turn varying duty cycle of switching device.

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Fig.8 User inputs data screen

The developed the interactive GUI software will be a promising and efficient tool for obtaining the corresponding duty ratio of the dc-dc converters of buck converter, boost converter and buck boost converter the Fig.8 shows user inputs data screen of developed

5.Results and discussion Matlab/Simulink Model of Boost Converter using designed values

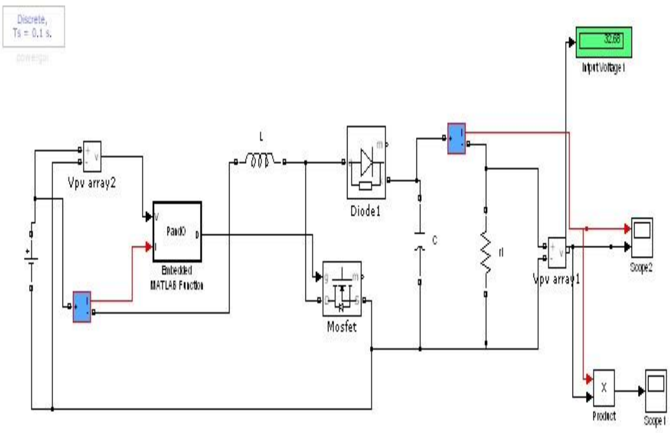

Fig 9. Simulink Model of Boost Converter

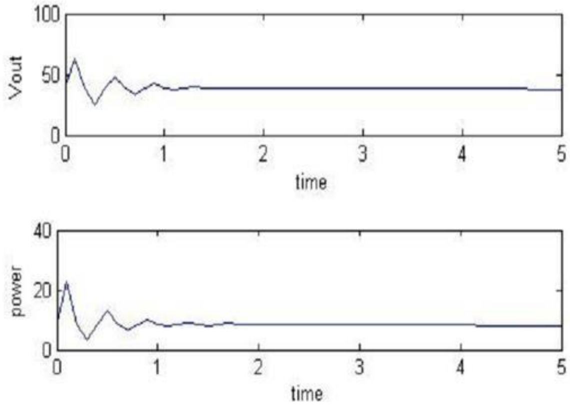

Fig.10 Output voltage and power of boost converter

Table 1. Solar panel test with resistive load of 100 ohm

V_{panel}(V)	I_{panel}(A)	P_{panel}(W)	PWM (%)	$V_{Boosted}$(V)	I_{load}(mA)	P_{Load} (W)
15.90	0.308	4.8	16	18.00	60.5	1.0
14.5	0.344	4.98	28	17.90	60.3	1.07
13.2	0.38	5.01	36	17.50	60.2	1.05
12.30	0.416	5.11	44	17.40	59.9	1.04
10.7	0.464	4.9	52	17.20	59.9	1.03
9.5	0.500	4.7	60	17.00	58.1	0.98
8.2	0.541	4.4	68	16.8	56.9	0.950
6.8	0.570	3.8	76	16.4	55.3	0.90
5.3	0.610	3.2	84	15.5	52.4	0.81
2.5	0.640	1.6	92	4.9	16.7	0.08
0.8	0.648	0.5	96	1.4	4.7	0.06

The following characteristics are analysed and verified.

a) PV panel power and PV voltage as a function of Pulse width modulation

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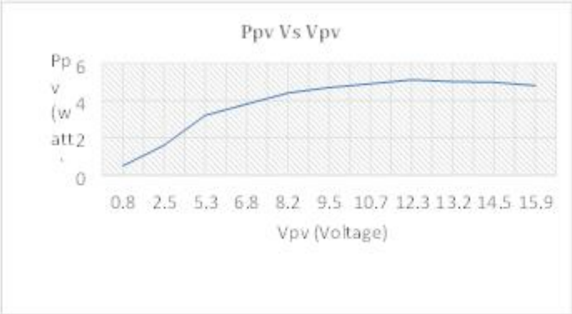

Fig.11 PV panel power and PV voltage as a function of Pulse width modulation

b) PV panel Voltage and PV current as a function of Pulse width modulation

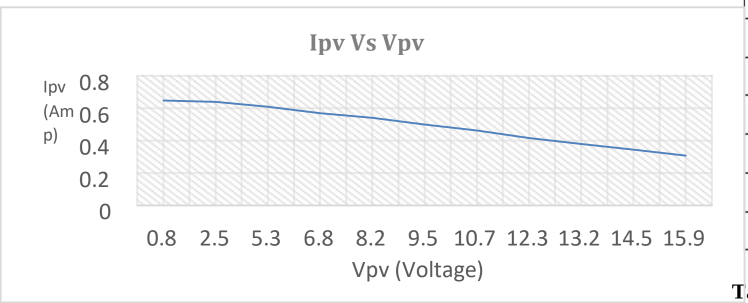

Fig. 12 PV panel Voltage and PV current as a function of Pulse width modulation

c) Ipv Vs duty cycle

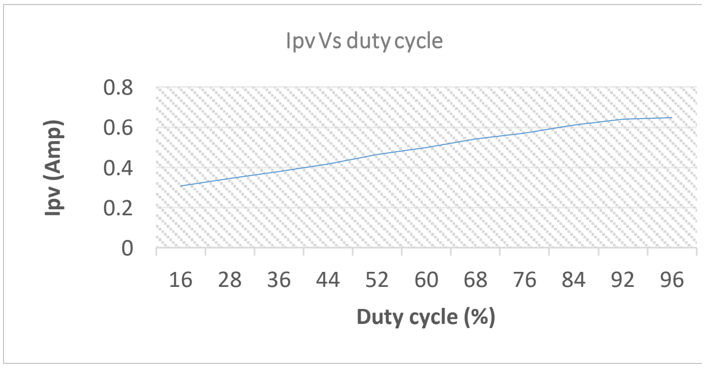

Fig.13 Ipv Vs duty cycle

Table 2 PV Voltage sensor test with input Voltage V = 21 Volt

Sl No	Voltage Measured from Multimeter (in Volts) through Voltage divider network	Voltage Measured from Multimeter (in Volts) In put Voltage (Vpv)	Analog Value Measured from ATMEGA 328	Voltage Measured from ATMEGA328 (in Volts corresponding to Analog value)	Voltage measured from ATMEGA328 (in Volts corresponding to 21 V ie Vpv)	Difference (in volts) Measured from Multimeter and Microcontroller		% Difference in Percentage (%)	
						With respect to 5 V	With respect to 21V	With respect to 5 V (%)	With respect to 21V (%)
1	0.512	2.132	104	0.508	2.130	0.004	0.003	0.08	0.014
2	1.012	4.183	204	0.997	4.180	0.015	0.003	0.3	0.014
3	1.504	6.275	306	1.495	6.270	0.009	0.005	0.18	0.023
4	2.085	8.694	423	2.067	8.690	0.018	0.004	0.36	0.019
5	2.527	10.566	515	2.517	10.560	0.010	0.006	0.2	0.028
6	3.047	12.755	622	3.040	12.750	0.007	0.005	0.14	0.023
7	3.538	14.722	718	3.509	14.720	0.029	0.003	0.58	0.015
8	4.050	16.934	826	4.037	16.930	0.013	0.004	0.26	0.019
9	4.560	19.022	929	4.540	19.020	0.020	0.002	0.40	0.009
10	4.990	20.996	1020	4.985	20.990	0.005	0.006	0.10	0.028

Table 3. PV Voltage sensor test with Input Voltage V = 42 Volt

Sl No	Voltage Measured from Multimeter (in Volts) through Voltage divider network	Voltage Measured from Multimeter (in Volts) In put Voltage (Vpv)	Analog Value Measured from ATMEGA 328	Voltage Measured from ATMEGA328 (in Volts corresponding to Analog value)	Voltage measured from ATMEGA328 (in Volts corresponding to 42 V ie Vpv)	Difference (in volts) Measured from Multimeter and Microcontroller		% Difference in Percentage (%)	
						With respect to 5 V	With respect to 42V	With respect to 5 V (%)	With respect to 42V (%)
1	0.512	4.264	104	0.508	4.26	0.004	0.003	0.08	0.014
2	1.012	8.366	204	0.997	8.36	0.015	0.003	0.3	0.014
3	1.504	12.55	306	1.495	12.54	0.009	0.005	0.18	0.023
4	2.085	17.388	423	2.067	17.38	0.018	0.004	0.36	0.019
5	2.527	21.132	515	2.517	21.12	0.010	0.006	0.2	0.028
6	3.047	25.51	622	3.040	25.5	0.007	0.005	0.14	0.023
7	3.538	29.444	718	3.509	29.44	0.029	0.003	0.58	0.015
8	4.050	33.868	826	4.037	33.86	0.013	0.004	0.26	0.019
9	4.560	38.044	929	4.540	38.04	0.020	0.002	0.40	0.009
10	4.990	41.992	1020	4.985	41.98	0.005	0.006	0.10	0.028

Table.4 Testing of current sensor

Sl No	Voltage Measured from Multimeter (in Volts)	Analog Value Measured from ATMEGA 328 microcontroller	Current Measured from ATMEGA328 microcontroller (in Amp)	Difference (in Amp)	Difference in Percentage (%)
1	0.107	20	0.100	0.007	0.14
2	0.211	41	0.200	0.011	0.22
3	0.306	60	0.290	0.016	0.32
4	0.408	81	0.400	0.008	0.16
5	0.505	103	0.500	0.005	0.10
6	0.609	123	0.600	0.009	0.18
7	0.704	141	0.695	0.003	0.06
8	0.800	161	0.790	0.010	0.20
9	1.060	211	1.050	0.010	0.20
10	1.508	307	1.500	0.008	0.16
11	2.100	427	2.090	0.010	0.20
12	2.610	532	2.600	0.010	0.20
13	3.041	619	3.030	0.011	0.22
14	3.867	752	3.863	0.004	0.08
15	4.200	858	4.190	0.010	0.20
16	4.870	991	4.860	0.010	0.20

5.1 Results and discussions of conventional P&O algorithm

The table 5 illustrated the I-V and P-V characteristics of conventional P &O algorithm by using constant variation of duty cycle in

Table 5. I-V and P-V characteristics of conventional P&O algorithm

V_{pv}(V)	I_{pv}(A)	P_{pv}(W)	I_L(A)	V boosted	Boost converter Duty Ratio
18.50	0.15	2.775	0.12	22.2	Increasing or decreasing the duty ratio in constant steps of 2%
16.80	0.32	5.376	0.16	29.60	
16.00	0.36	5.76	0.17	30.70	
14.80	**0.40**	**5.92**	**0.17**	**31.00**	
9.60	0.43	4.128	0.14	25.30	

It has observed the PV panel operates at different point of operating and it varies accordingly insulation level, to extract the maximum power the algorithm per turb to search the MPP in step of constant duty ratio in turn vary the duty ratio of MOSFET, hence the algorithm takes several steps to perturb and reaches to MPP to extract power from the panel to the load.

Table.6 Results and discussions of 555 timer PWM with Single PV panel

Sl No	PWM generated through 555 timer circuit and PWM Varied for converter, recorded from CRO Duty ratio (%)	PV Panel voltage V_{pv} in voltage	PV Panel current I_{pv} in Current	PV panel power Ppv in watts	Load Current I_L in Current	Load Voltage V_L in voltage	Load power P_L in watts	Change in PV panel voltage in volts
1	25	16	2.1	33.6	0.45	25	11.25	
2	41.6	19	2.3	43.7	0.43	28	12.04	3
3	60	20	2.7	54	0.40	33	13.2	1
4	70	17	3.0	51	0.38	24	9.12	-3
5	77	15	3.2	48	0.35	22	7.7	-2

Table 7 Results and discussions of optimized P&O algorithm

Sl No	Vpv	Ipv	Ppv	I_L	V_L Boosted Voltage	Change in Voltage	Duty ratio (%) Varied through algorithm for converter for MPP Recorded from CRO and through serial port (Duty ratio in %)	Variation of duty ratio in step with respect to change in PV voltage
1	18.50	0.15	2.775	0.12	22.2		15	
2	16.80	0.32	5.376	0.16	29.6	-1.7	45	8
3	16.00	0.36	5.76	0.17	30.7	-0.8	49	3
4	14.80	0.4	5.92	0.17	31	-1.2	53	6
5	9.60	0.43	4.128	0.14	25.3	-5.2	63	10

Table 8 Optimized algorithm with two series connected PV panel varying load

Sl No	Duty ratio (%) Varied through algorithm for converter for MPP Recorded from CRO and through serial port (Duty ratio in %)	PV Panel voltage V_{pv} in voltage	PV Panel current I_{pv} in Current	PV panel power Ppv in watts	Load Current I_L in Current	Load Voltage V_L in voltage	Load resistance R_L in Ohm	Change in PV panel voltage in volts
1	70	18	2.1	37.8	0.29	31	100	
2	61	17	2.3	39.1	0.5	25	50	-1
3	66	21	2.7	56.7	0.40	29	70	4
4	58	20	2.9	58	0.61	25	40	1
5	77	21	2.1	44.1	0.33	23	190	1
6	67	19	2	38	0.3	30	90	-1
7	17	15	2.2	33	0.85	18	10	- 4
8	73	10	2.4	24	0.39	27	60	-5
9	69	19	2.6	49.4	0.35	30	80	9

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Table 9 Optimized algorithm with two series connected PV panel with constant load 100ohm

Sl No	Duty ratio (%) Varied through algorithm for converter for MPP Recorded from CRO and through serial port (Duty ratio in %)	PV Panel voltage V_{pv} in voltage	PV Panel current I_{pv} in Current	PV panel power Ppv in watts	Load Current I_L in Current	Load Voltage V_L in voltage	Load power	Change in PV panel voltage in volts
1	72	20	2.6	52	0.75	33	24.75	
2	72	18	2.4	43.2	0.70	29	20.3	- 2
3	78	13	2.7	35.1	0.65	25	16.25	-5
4	80	12	3	36	0.62	22	13.64	-1
5	82	10	3.3	33	0.42	21	8.82	-2
6	75	15	2.6	39	0.38	28	10.64	5
7	70	17	2	34	0.40	27	10.8	2
8	72	20	2.6	52	0.63	30	18.9	5
9	71	19	2.4	45.6	0.60	29	17.4	-1

5.2 GUI result validation of optimized algorithm of two series connected PV panel of varying load

The results obtained from hardware are validated with GUI based developed software results are tabulated in below tables the design consideration of GUI software are discussed in section 2.3, the duty ratio of the converter is obtained from the optimized algorithm recorded through the serial port and CRO which are compared with computed value from GUI software

Table 10 GUI result validation of optimized algorithm of single PV panel with varying load

Sl No	Vpv	Ipv	Load resistance R_L	Duty ratio (%) Varied through algorithm for converter for MPP Recorded from CRO and through serial port	Duty ratio (%) Computed from GUI for MPP
1	9.66	0.38	100	49	49.58
2	9.46	0.34	110	49	49.70
3	9.6	0.32	120	51	50
4	9.7	0.33	130	51	52.4
5	9.8	0.32	140	53	53.22
6	7.9	0.34	150	59	60.64
7	9.8	0.3	160	54	54.81
8	9.95	0.3	170	54	55.83
9	9.99	0.29	180	56	56.25
10	8.16	0.32	190	63	63.36
11	10.1	0.28	200	57	57.53

Table 11 Validation of result with GUI (Single PV panel of constant load of 176 ohm)

Sl No	Vpv	Ipv	Duty ratio (%) Varied through algorithm for converter for MPP Recorded from CRO and through serial port	Duty ratio (%) Computed from GUI for MPP
1	18.50	0.15	16	16.28
2	16.80	0.32	45	45.38
3	16.00	0.36	49	49.00
4	14.80	0.4	53	54.14
5	9.60	0.43	64	64.38

Table 12 Validation of result with GUI (two series connected PV panel of varying load)

Sl No	Vpv	Ipv	Load resistance R_L	Duty ratio (%) Varied through algorithm for converter for MPP Recorded from CRO and through serial port	Duty ratio (%) Computed from GUI for MPP
1	18	2.1	100	69	70.72
2	17	2.3	50	62	61.55
3	21	2.7	70	64	66.66
4	20	2.9	40	56	58.47
5	21	2.1	190	78	77.05
6	19	2	90	69	67.51
7	15	2.2	10	17	17.42
8	10	2.4	60	72	73.64
9	19	2.6	80	69	69.77

Table 13 Validation of result with GUI (two series connected PV panel with constant load of 100 Ohm)

Sl No	Vpv	Ipv	Duty ratio (%) Varied through algorithm for converter for MPP Recorded from CRO and through serial port	Duty ratio (%) Computed from GUI for MPP
1	20	2.6	71	72.26
2	18	2.4	72	72.61
3	13	2.7	79	78.05
4	12	3	81	80
5	10	3.3	81	82.59
6	15	2.6	74	75.98
7	17	2	72	70.84
8	20	2.6	73	72.26
9	19	2.4	71	71.86

6. Conclusion

In this paper the author has investigated how the maximum power can extract from PV module through the dc-dc converters, the research focused on developing MPP control algorithm for PV system to extract maximum power form PV panel to the load with irrespective of sudden change of irradiance the non-linearity characteristics of PV panel taken in to consideration and developed the algorithm, the protection issue of panel also considered and suitable algorithm is developed , the boost converter designed and Matlab/Simulink simulation has carried out to verify the designed value. The proposed MPP algorithm has more speed to achieve the maximum power point and less oscillation around MPP which prevent or minimize the loss which occurs in PV module. The experimental hardware setup is done using Arduino 328p microcontroller. the results were tested with constant and variable loads for single and two PV panels are connected in series. The obtained results wear compared with GUI based developed software the results are more close to the maximum power point irrespective of PV input voltage.

The future work can be carried out using different dc-dc converter such as synchronous buck or buck boost converter with different irradiance and temperature and also by creating a hybrid algorithm that is combine with fuzzy logic or neural network and finding the way which is very effective to track the MPP.

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