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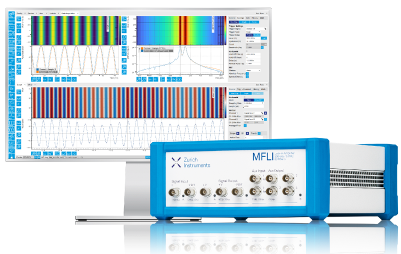

Parallel Full-Bridge DC-DC Converter Using Maximum Power Point Tracker (MPPT) for Water Pump Loads

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Abstract. This paper shows that the design and implementation of a parallel full bridge DC-DC converter for a maximum power point tracker (MPPT) system with an incremental conductance method. This system consists of a parallel full-bridge DC-DC converter that will increase the output voltage of solar panels with a power of 3x200 WP. The output voltage of the converter will be converted into AC voltage by single phase inverter by using SPWM switching. The results of this system will be used to supply the water pump loads with a power is 125 watts and a frequency of 50 Hz. The system used is able to increase the output power of solar panels with an average value of 19.68% for a 100 watts incandescent lights arranged in series, the load using a water pump with no load conditions that is equal to 35.91%, while the load using a water pump with load conditions that is equal to 21.19%.

INTRODUCTION

Solar energy is a renewable energy source. At this time solar energy has become one of the solutions for electrical energy sources that are environmentally friendly. Solar energy has several advantages including no noise, easy installation, and does not require additional maintenance costs. These advantages make solar energy one of the main choices as an alternative electric energy source [1-3]. But solar energy also has drawbacks, including requiring high installation costs, low efficiency and non-linear characteristics so MPP tracking is needed. The power conditioning system is a key component of a PV system that is not only able to convert PV output power into AC power but also uses MPPT controls that allow the system to achieve maximum power [4-6]. With the MPPT system, PV will be able to work at the maximum point in every condition. This advantage will greatly impact on cloudy weather conditions. There are several types of maximum power point tracking methods including (1) perturb and observe method, (2) incremental conductance method, (3) artificial neutral network method, (4) fuzzy logic method, (5) peak power method, (6) open circuit voltage method, and (7) temperature method, etc. [7,8]

This system uses MPPT control with an incremental conductance method by using a converter in the form of a parallel full-bridge DC-DC converter that is integrated with a single-phase inverter to convert DC voltage to AC voltage [9-11]. There are several reasons for choosing a parallel system in the power converter circuit. The current or power ratings of available components (semiconductor components, core transformers) may not be able to supply the power requirements of the converter. The solution to this condition is by connecting components in parallel, paralleling a portion of the circuit or paralleling the entire converter. High power requirements and operating reliability are also reasons for parallel converter configurations [12-14]. In this system the main reason for using a parallel configuration in a converter is to obtain a component value with a rating that is easier to achieve [15]. The transformers in parallel configurations have a lower rating value, making it easier for the design and manufacturing process [16-20].

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METHOD

The solar panels used in this system are two solar panels with a power of 200 WP each. The three solar panels used are installed in series. The output voltage of the solar panel will be increased by using a parallel full-bridge DC-DC converter. The output of the solar panels is maintained to remain at the maximum operating point with MPPT control using the incremental conductance method. The single-phase inverter is used to convert DC voltage from converter output to AC voltage which will be used to supply a water pump with a power of 125 watts of frequency 50 Hz. This system is illustrated in Fig. 1.

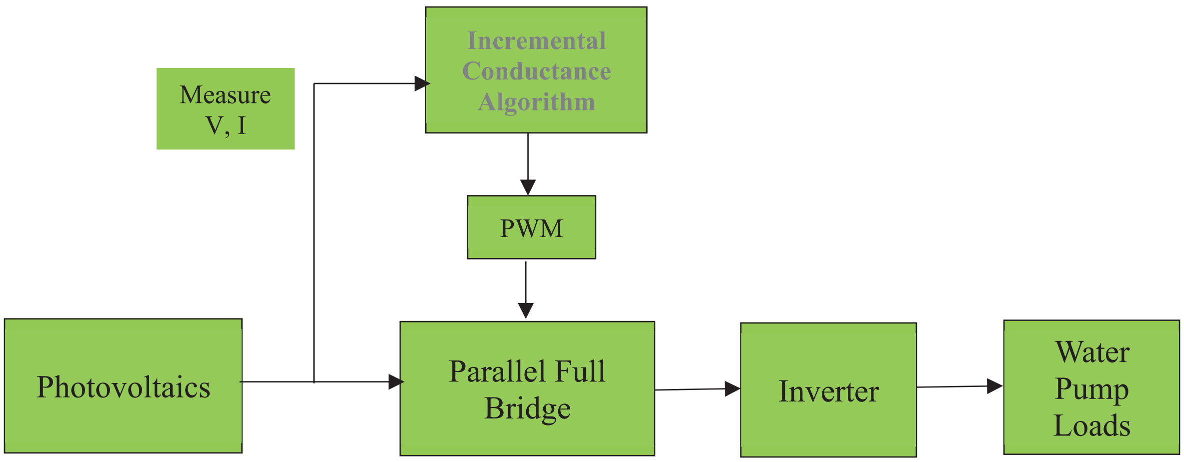

FIGURE 1. Block Diagram System

The basic concept of the incremental conductance method is in accordance with the characteristic curve of the solar panel shown in Fig. 2 and the Fig. 3 is the flowchart of incremental conductance methods. The slope value of the solar panel power curve will be zero when it reaches MPP point, the slope value will increase according to the right side of MPP, and it will increase as needed left point MPP. The basic equations of this method are according to equations (1), (2) and (3) below:

$$\frac{dP}{dV} = 0 \text{ , on MPP point} \quad (1)$$

$$\frac{dP}{dV} < 0, \text{ right side of MPP point} \quad (2)$$

$$\frac{dP}{dV} > 0, \text{ left side of MPP point} \quad (3)$$

The value of $\frac{dP}{dV}$ is the factor of identification of the maximum power point. By using the value of these factors, the incremental conductance method is expected to be able to track the MPP point of PV effectively [21-22]. Based on the power equation, equation (4) is obtained.

$$\frac{dP}{dV} = \frac{[d(V.I)]}{dV} \quad (4)$$

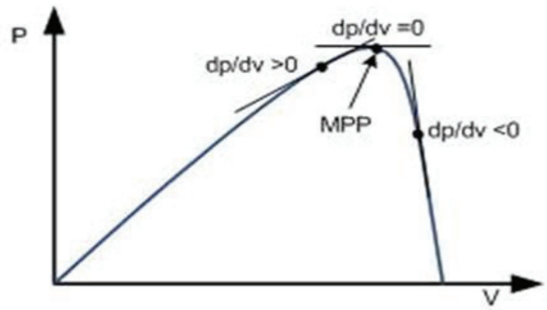

FIGURE 2. The basic concept of incremental conductance on the PV curve.

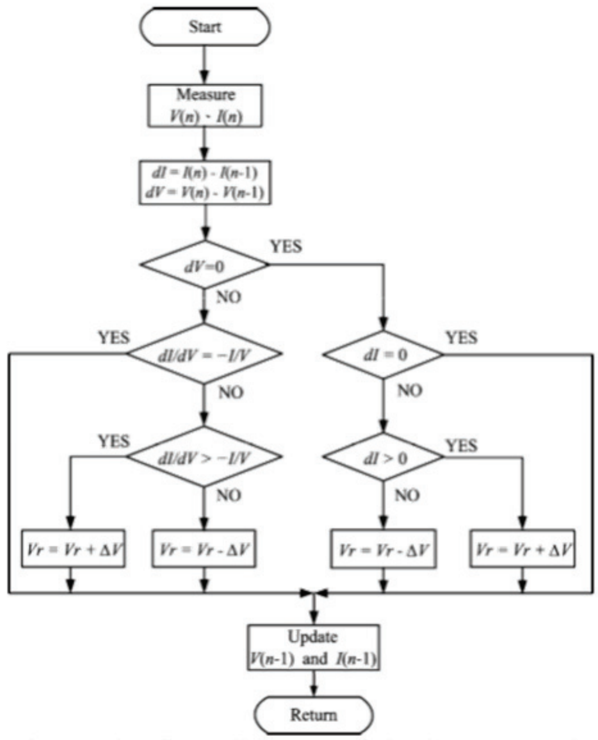

FIGURE 3. The flowchart of incremental conductance method.

The above equation can be written with the provision V is the voltage of the solar panel and I is the current of the solar panel, according to equation (5).

$$\frac{dI}{dV} = -\frac{I}{V} \tag{5}$$

Based on equations (1), (2), (3) and equation (5), they are obtained,

$$\frac{dI}{dV} + \frac{I}{V} = 0, \textit{ on MPP point} \tag{6}$$

$$\frac{dI}{dV} + \frac{I}{V} > 0, \textit{ right side of MPP point} \tag{7}$$

$$\frac{dI}{dV} + \frac{I}{V} < 0, \textit{ left side of MPP point} \tag{8}$$

In the MPP system, it is never separated from the choice of type of converter topology to be used. The converter used in this system is a parallel full-bridge DC-DC converter. Figure 4 shows a circuit from a parallel full-bridge DC-DC converter. Two full-bridge converters will be paralleled to the input of a high frequency transformer and two high frequency transformers will be connected in parallel, so that the current flowing will be divided in two and there is no transformer with a large power capacity is needed [23].

The output voltage of a full-bridge DC-DC converter can be calculated by equation (9).

$$V_{out} = 2\frac{N_s}{N_p}V_{in}D \tag{9}$$

The full-bridge converter consists of several circuit blocks, namely: a full-bridge inverter, transformer, rectifier, and filter circuit. The working process of this converter starts from the switching process carried out by the inverter. **FIGURE 5.** shows the conventional switching sequence of converters.

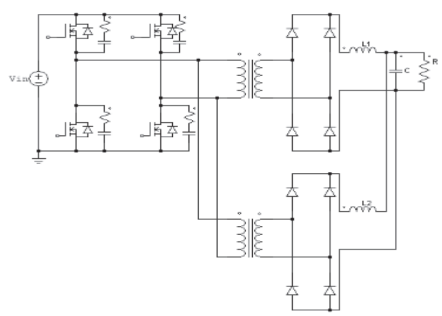

FIGURE 4. The parallel full-bridge DC-DC converters circuit.

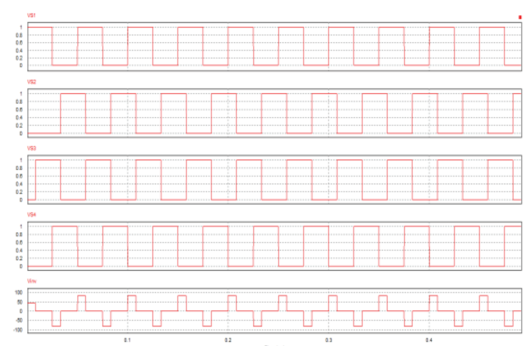

FIGURE 5. The switching sequence in the parallel full-bridge DC-DC converter.

The calculation of the ratio of the required transformer turns is shown in equation (10).

$$V_o = 2 \times V_s \times \left(\frac{N_2}{N_1}\right) \times D \tag{10}$$

The inductor used is two pieces which are then connected in parallel, so that the current flowing in each inductor will be divided into two. The calculation of the inductor and capacitor value needed will be shown in equation (11) and (12).

$$L = \frac{1}{2f} \times (V_s - V_o) \times \frac{V_o}{V_s} \times \frac{1}{\Delta I_L} \quad (11)$$

$$\Delta V_o = \frac{(1-D)V_o}{8LC(2f)^2} \quad (12)$$

RESULTS AND DISCUSSION

The converter used in this system is designed according to the parameters shown in Table 1**.** for a parallel full-bridge DC-DC converter. The parameters in Table 1. are designs for converters to increase dc input voltage by 75 volts to 311 volts. The converter is designed with a maximum duty cycle value of 45% with a maximum input power of 400 watts. This test is carried out in an open loop with a fixed duty cycle value and a changing input voltage value. The values observed in this test are the output voltage and output current of the converter. The results of this test can be known the working ability of the converter. Based on the test results in Table 2**.**, it is known that the converter is able to increase the voltage with the output voltage approaching the value of the output theory.

TABLE 1. The parameters of parallel full-bridge DC-DC converter.

Parameters	Value
Input voltage	75
Output voltage	311
Frequency Switching	20 kHz
Transformer T_1	N_1: N_2 = 1:5
Transformer T_1	N_1: N_2 = 1:5
Inductor L_1	10.31 mH
Inductor L_2	10.31 mH
Diode (D_1, D_2, D_3, D_4)	STTH60L06CW
Switch (Q_1,Q_2,Q_3,Q_4)	IGBT
Capasitor	4.167 μF

TABLE 2. The results of testing a parallel full-bridge DC-DC converter.

Vin (volt)	Iin (A)	Vout (volt)	Iout (A)	Pin (watt)	Pout (watt)	Error (%)	η (%)
82.5	7.28	360	1.4	600.6	504	3.03	83.9
70	6.5	305	1.3	455	396.5	3.17	87.14
60	5.7	256	1.2	342	307.2	5.18	89.82
50	5.3	210	1.1	256	231	6.67	87.16
40	4.8	169	0.95	198	160.5	6.11	81.08
30	4	125	0.8	120	100	11.11	83.33
20	3.2	81	0.67	64	54.24	10	84.75
10	2.2	36.1	0.5	22	18.08	19.62	82.2

The second test is carried out with the condition of the integrated system in the open loop condition. The output voltage of the converter will be the input voltage on a single-phase inverter. The parameters used for the design of a single-phase inverter are shown in Table 3. In this second test, the observed value is the converter output voltage, converter output current, inverter output voltage and inverter output current. The test results are shown in Table 4., the output waveform of the inverter circuit is shown in Fig. 6 (time / div = 2.5ms). In this test, the load is in the form of a water pump in a non-load condition.

TABLE 3. The single-phase inverter parameters.

Parameter	Nilai
Input voltage	311
Output voltage	220
Output Frequency	50 Hz
Diode (D_1, D_2, D_3, D_4)	FR307 (fast recovery diode)
Switch (Q_1,Q_2,Q_3,Q_4)	IGBT

TABLE 4. Open loop integration test results with a load of water pumps that are not burdened.

Vin (volt)	Iin (A)	Vdc (volt)	Idc (A)	Vac (V)	Iac (A)
75	2.79	323	0.36	255	1.3
70	2.29	302.1	0.32	235	0.9
65	1.95	281.3	0.26	220	0.75
50	1.69	262	0.23	200	0.6
55	1.49	237.6	0.29	185	0.4

In the third test, an integrated system with load testing was carried out in the form of two 100 watts lamps arranged in series in close loop conditions using MPPT incremental conductance control. In this test will be compared the value of input power on the system without MPPT control with the system using MPPT control. The MPPT control system has a duty cycle value that changes according to the maximum working point of the solar panel, while the MPPT control system has a fixed duty cycle value. The results of this integration test are shown in Table 5. Based on the results of this test, the results of the increase in input power in the system with MPPT control are obtained.

The data in Table 5. are presented in graphical form in Fig. 7. In this graph, there is a significant change in the input power of the solar panels. Based on these results it is known that the MPPT incremental conductance method is able to track the MPP value of solar panels so that solar panels can work in maximum points automatically. Based on the test results, the average value of power increase using a 100 watts incandescent lamp connected to the series is 19.68%.

TABLE 5. The results of testing the system integration in close loop conditions with the load of two 100 watts lamps arranged in series.

Hour	Without MPPT Control					Using MPPT Control					The Increase Power (%)
	Vin (V)	Iin (A)	Vout (V)	Iout (A)	Pin (watt)	Vin (V)	Iin (A)	Vout (V)	Iout (A)	Pin (watt)	
09.00	74	1,4	261,5	0,3	103,60	72,8	1,82	312,5	0,32	132,50	21,81
09.15	74	1,4	261	0,3	103,60	72,5	1,82	312,2	0,33	131,95	21,49
09.30	72,2	1,37	258	0,29	98,91	66,5	1,73	253,1	0,31	115,05	14,02
09.45	75,1	1,41	266	0,3	105,89	73	1,83	311,6	0,31	133,59	20,73
10.00	75,9	1,42	268,4	0,3	107,78	75,8	1,87	315,5	0,33	141,75	23,96
10.15	76,2	1,42	269,3	0,3	108,20	74,3	1,85	320	0,33	137,46	21,28
10.30	73,8	1,4	260,1	0,29	103,32	72,2	1,82	310,7	0,32	131,40	21,37
10.45	74,8	1,41	264	0,3	105,47	73,3	1,83	315	0,33	134,14	21,37
11.00	75,1	1,42	265,2	0,3	106,64	74	1,85	318,4	0,33	136,90	22,10
11.15	73,9	1,4	261,5	0,3	103,46	72,9	1,83	314,1	0,33	133,41	22,45
11.30	73,5	1,39	259,5	0,29	102,17	72,1	1,82	310,1	0,32	131,22	22,14
11.45	73,2	1,39	258,6	0,29	101,75	72	1,81	309	0,32	130,32	21,92
12.00	73,2	1,5	258,3	0,29	109,80	72	1,82	310,3	0,31	131,04	16,21
12.15	73,8	1,4	260,8	0,29	103,32	72,6	1,82	310,3	0,32	132,13	21,81
12.30	73,5	1,39	260	0,29	102,17	72,2	1,82	310,2	0,32	131,40	22,25
12.45	73,7	1,4	260,8	0,29	103,18	73,3	1,83	314,9	0,33	134,14	23,08
13.00	74,3	1,4	262,5	0,3	104,02	72,8	1,83	312,9	0,33	133,22	21,92
13.15	74,1	1,4	262,3	0,29	103,74	72,7	1,83	311,5	0,33	133,04	22,02
13.30	74	1,4	261,3	0,29	103,60	72,5	1,82	311,2	0,33	131,95	21,49
13.45	74,5	1,41	263,2	0,3	105,05	78,96	75,17	312,6	0,33	133,04	21,04
14.00	74,6	1,41	263,7	0,3	105,19	79,11	75,21	313,4	0,33	133,41	21,15
14.15	74,1	1,4	262,1	0,29	103,74	76,01	73,27	311,9	0,33	132,49	21,70
14.30	74	1,4	260,2	0,3	103,60	78,06	75,35	302,1	0,32	132,13	21,59
14.45	73,6	1,39	260,2	0,3	102,30	78,06	76,30	304,5	0,32	128,16	20,17
15.00	73	1,39	258	0,29	101,47	74,82	73,74	299,1	0,32	124,07	18,21
15.15	73,2	1,39	258,6	0,29	101,75	74,99	73,71	298,6	0,32	124,24	18,11
15.30	70	1,34	250,5	0,28	93,80	70,14	74,78	281	0,31	113,86	17,62
15.45	71,4	1,36	251,6	0,29	97,10	72,96	75,14	265,6	0,3	104,35	6,94
16.00	67,8	1,32	238,5	0,28	89,50	66,78	74,62	238,5	0,28	89,50	0,74

The fourth test is an integrated system testing in close loop conditions with a load in the form of a water pump. The water pump used is a water pump with 125 watts of power and a frequency of 50 Hz. The converter will be used to supply a single-phase SPWM inverter. The value of the converter duty cycle will be adjusted automatically using the MPPT control incremental conductance method and will be compared with the value of the solar panel output power with the converter condition the fixed duty cycle value. Table 6. is the result of testing using a load in the form of a water pump. This test shows that the average value of power increase in the load using a water pump in a non-load condition is 35.91%, while the load uses a water pump with a load condition that is equal to 21.19%.

FIGURE 6. The wave of inverter output.

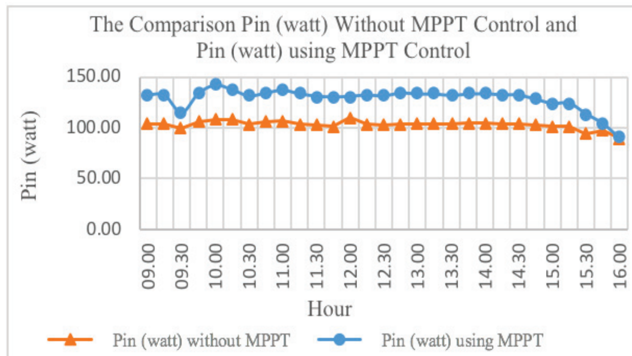

FIGURE 7. The comparison of Pin (watts) without MPPT controls and Pin (watts) with MPPT controls

TABLE 6. The results of testing the system integration in a close loop condition with a water pump load.

Load	Without MPPT Control					Using MPPT Control					The Increase Power (%)
	Vin (V)	Iin (A)	Vout (V)	Iout (A)	Pin (watt)	Vin (V)	Iin (A)	Vout (V)	Iout (A)	Pin (watt)	
Water pump with no load conditions	76,2	1,55	267,6	0,288	118,11	73,1	2,52	308,4	0,421	184,21	35,88
	75,3	1,65	296,8	0,314	124,24	72,4	2,64	306,4	0,442	191,13	35,00
	76,0	1,58	256,1	0,323	120,08	73,1	2,56	309,4	0,435	187,13	35,83
	76,5	1,52	264,3	0,308	116,28	73,3	2,54	310,9	0,433	186,18	37,54
	75,7	1,62	258,8	0,311	122,63	72,6	2,65	309,2	0,453	192,39	36,26
	75,3	1,66	255,3	0,319	12,99	72,3	2,64	307,9	0,451	190,87	34,52
	74,0	1,71	247,8	0,336	126,5	71,2	2,73	304,8	0,464	194,37	34,90
	75,4	1,66	260,8	0,316	125,16	72,5	2,66	307,9	0,443	192,85	35,10
	76,6	1,51	262,1	0,288	115,66	73,3	2,53	287,7	0,472	185,70	37,72
	76,2	1,54	257,8	0,294	117,34	73,2	2,52	268,3	0,492	184,46	36,39
Water pump with load conditions	72,1	1,94	246,2	0,402	139,87	70,0	2,62	293,0	0,466	183,40	23,74
	72,4	1,92	248,1	0,415	139,00	70,3	2,60	296,9	0,458	182,78	23,95
	72,2	1,93	250,5	0,402	139,34	70,1	2,61	298,2	0,458	182,96	23,84
	71,4	2,30	247,5	0,480	164,22	69,5	2,97	296,6	0,516	206,41	20,44
	71,8	2,50	250,2	0,521	179,50	71,2	2,88	301,3	0,487	205,60	12,69
	73,2	1,87	254,3	0,400	136,88	71,1	2,55	278,8	0,92	182,30	24,92
	72,5	1,91	251,3	0,403	138,47	70,7	2,58	301,1	0,453	182,40	24,08
	72,3	1,93	251,7	0,402	139,53	70,4	2,62	297,9	0,439	184,44	24,35
	72,0	1,95	252,2	0,404	140,40	70,0	2,63	296,6	0,463	184,10	23,74
	71,7	2,51	247,8	0,533	179,96	71,1	2,84	308,8	0,488	202,56	11,16

SUMMARY

The highest output voltage from the condition of the solar panel when using the MPPT control is 75.8 volts using a 100 watts lamp, and it can be increased by the converter circuit to 315.5 volts. The condition when the water pump is not loaded is 73.3 volts, and it can be increased by the converter to 310.9 volts. However, the condition when the water pump is loaded is 71.2 volts, and it can be increased by the converter circuit to 301.3 volts.

The inverter is able to change the output voltage of parallel full-bridge DC-DC converter from 310.9 volts to 215 volts AC voltage for the water pump when not loaded and is able to change the output voltage from 301.3 volts to 202 volts AC voltage for the water pump when loaded.

Solar panels with MPPT control using the incremental conductance method can produce a greater output power when compared to without using controls. The increase in the average output power produced using MPPT control is 19.68% when conditions with two a 100 watts incandescent lights arranged in series, while the average output power when the load using a water pump with no load conditions that is equal to 35.91%, and the average output power when the load using a water pump with load conditions that is equal to 21.19%.

The output power produced by solar panels can be influenced by light intensity and surface temperature of solar panels. In addition, the output power produced by solar panels can also be affected by loads. The highest output power produced by solar panels with two a 100 watts incandescent lights arranged in series is 194.37 watts, when the load using a water pump with no load conditions is 141.75 watts, and the load using a water pump with load conditions is 206.41 watts.

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