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Modeling and Simulation of MPPT-SEPIC Combined Bidirectional Control Inverse KY Converter Using ANFIS in Microgrid System

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Abstract

Photovoltaic system (PV) is widely used in various renewable energy application. The main problem of PV system is how to get the maximum output power which is integrated in microgrid system. Furthermore, the redundancy output power generated by on a distribution system should also be considered. This study utilizes the excess power for energy storage using bidirectional of KY inverse converter. Since the DC voltage which generated by PV and the energy storage will be converted into AC voltage using inverter toward load. This paper proposes ANFIS as search optimization method using SEPIC converter with a maximum efficiency of 99.95% to impact to power generation performance in microgrid system.

Keywords*:* *Photovoltaic, Bidirectional of KY Inverse Converter, SEPIC Converter, Maximum Power Point Tracking (MPPT), Inverter, ANFIS*

1. Introduction

As the development of high energy demand lead to the availability of fossil fuels are diminishing. This requires in studies in the field of renewable energy as an alternative fuel fossil discussion is required [22-23]. Research in the field of renewable energy is growing rapidly, especially research on Photovoltaic and modelling [1-3]. Hence a lot of studies to modeling PV continues on optimizing the generated power. The optimization of power on PV known as Maximum Power point tracking (MPPT) which is being applied in microgrid system.

Studies on MPPT by comparing several methods such as hill climbing/P&O, incremental conductance, fractional open circuit voltage, short circuit fractional voltage, fuzzy logic control, the current sweep, load voltage maximization, and dP/dI feedback control have been conducted [4]. In addition to these methods there are also other methods are used to maximize the PV MPPT using artificial intelligence such as PSO [5], ANFIS [6].

In this case have been developed methods to maximize the power output of PV. The problems that appear when the PV is connected to a microgrid system is how to utilize the excess the power generated by PV. Excess power generated by PV is important to be consider. From these problems there are a lot of research being done to overcome the excess power generated by optimally utilizing the excess power.

Several previous studies that discuss the parallel connection between the PV and battery are each connected to the converter [7], Operation Bidirectional buck-boost converter with MPPT in a distribution system [8], the strategy in increasing the battery lifetime connected with PV [9], the application of AC-DC micro grid system which connected to the PV, energy storage, and considering the influence of the critical load [10], as well as applications in hybrid electric cars connected with PV and energy storage [11].

After a lot of studies that discuss the connection of PV with energy storage research emerges about merging MPPT using P&O with bidirectional converter as a bridge to the battery and DC bus generated by the PV and battery are converted into a voltage distribution conditioned by the inverters in the form of simulation and implementation [12-14]. This paper proposes study of the collective MPPT using ANFIS with bidirectional converter as a bridge to

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the battery and DC bus generated by the PV and battery is converted into AC by an inverter voltage distribution to the load [15]. Subsystems of the MPPT-Bidirectional is shown in Figure 1.

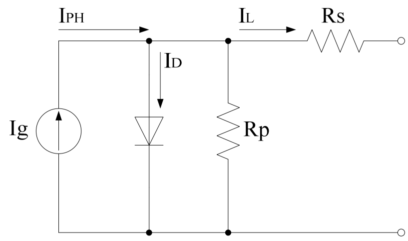

Figure 1. Standard equivalent circuit of a PV cell

2. Research Method

The PV module consist of multi cells which generate DC voltage when it is exposed to light. Generally, a PV module can be comprised of 36 cells or 72 cells. The output power of the PV modules is affected by light radiation and temperature. A long with the increase of light radiation, the greater the output power can be generated by the PV module and vice versa. In this paper,the 10 PV modules are used in microgrid system. Each PV module power is 200 Watt, which are connected in series so that the total output power is 2000 Watts is shown in Table 1. By connecting in series, the voltage of the PV modules will increase with the number of PV modules connected in series. Using standard equivalent circuit of a PV cell shown in Figure 2, current-voltage (I-V) characteristic equation of *p* parallel strings with *s* series cells per string is developed from (1) to (5) as below [1].

$$I_L = I_{PH} - I_S\left[\exp\left(\frac{qV_d}{AK_BT}\right) - 1\right] - \frac{V_d}{R_{SH}} \quad (1)$$

$$I_{PH} = \left[I_{SC} + K_1\left(T_C - T_{Re\,f}\right)\right]G \quad (2)$$

$$I_S = I_{RS}\left(\frac{T_C}{T_{Re\,f}}\right)^3 \exp\left[qE_B\left(\frac{1}{T_{Re\,f}} - \frac{1}{T_C}\right)/\ K_BA\right] \quad (3)$$

$$I_{RS} = \frac{I_{SC}}{[\exp\left(\frac{qV_{OC}}{N_SKAT_C}\right) - 1]} \quad (4)$$

$$I_L = N_PI_{PH} - N_PI_S[\exp(qV/N_SKT_CA) - 1] \quad (5)$$

Where, $I_{PH} = photo - current$,
$I_L = current\ at\ the\ output\ terminal$,
$I_S = saturation\ current\ of\ the\ diode$,
$I_{RS} = reverse\ saturation\ current$,
$T_C = cell\ working\ temperature$,
$T_{ref} = reference\ temperature$
$R_s\ =\ series\ resistance$,
$K_B = Boltzman\ constant$,
$V_d = diode\ voltage$,
$G = solar\ insolation$
$q = electron\ charge$

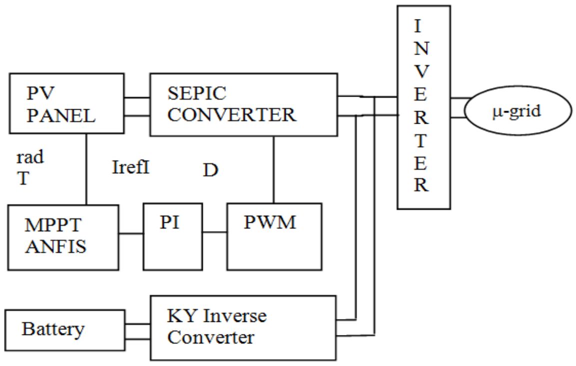

Figure 2. Subsystems of the MPPT-Bidirectional

Table 1. PV Panel Spesification [21]

Parameter	Nilai
Maximum Power (Pmax)	200 W
Voltage @ Pmax (Vmp)	24.5 V
Current @ Pmax (Imp)	8.16 A
Guranteed minimum Pmax	182 W
Short-circuit Current (Isc)	8.7 A
Open-circuit Voltage (Voc)	30.8 V
Temperature coefficient of Voc	-(111 ± 10) mV/^{o}C
Temperature coefficient of Isc	(0.065 ± 0.015)%/^{o}C
NOCT2	47 ± 2^{o}C

3. Modeling of Sepic Converter and MPPT Controller

3.1. Sepic Converter Modeling

Sepic converter is the development of a buck-boost converter with the same function that raising and lowering the voltage. The difference is that the voltage generated by the Sepic converter is positive. In this paper, the SEPIC converter is used as an MPPT to optimize the power output of PV Module. Equation (6) to (10) are used to modeling sepic in Continuous Conduction Mode [16]. Sepic specification and design parameters are shown in Table 2.

$$V_o = V_{IN}\frac{D}{1-D} \tag{6}$$

$$L_1 = \frac{V_{IN}\times D}{\Delta i_{L1}\times f_s} \tag{7}$$

$$L_2 = \frac{V_{IN}\times D}{\Delta i_{L2}\times f_s} \tag{8}$$

$$C_o = \frac{D}{R\times\frac{\Delta V_O}{V_O}\times f_s} \tag{9}$$

$$C_o = \frac{D}{R\times\frac{\Delta V_{C_S}}{V_O}\times f_s} \tag{10}$$

Switching frequency used is 40 KHz to minimize inductance value of L1 and L2. By using high-frequency output signal generated by the SEPIC converter output will be smooth. Overall calculation of the SEPIC converter is almost the same as the calculation of the Buck-boost converter.

Table 2. SEPIC Spesification and Design Parameters

Parameter	Symbol	Value	Unit
Input Voltage	*Vin*	245	V
Switching Frequency	*fs*	40	KHz
Output Voltage	*Vo*	400	V
Rated Output Power	*Po*	2000	W
Current Ripple	ΔI_L	5%	A
Voltage Ripple	ΔV_o	5%	V
Inductor 1	*L1*	9.8	mH
Inductor 2	*L2*	9.8	mH
Coupling Capacitor	*Cs*	20	uH
Output Capacitor	*Co*	20	uH

3.2. MPPT Controller Modeling

The block schematic of the ANFIS MPPT is shown in Figure 2. Data set for the ANFIS is irradiance and temperature. Output for the ANFIS is Ireference. In this paper each membership function consists of 7 triangles so that the resulting output is more precise and accurate. ANFIS is a controller that combines the advantages possessed by the fuzzy controller [22] and neural network, so fuzzy built on neural network system as shown in Figure 3. As with neural network system, ANFIS also conducts training data. Data is obtained from the curve characteristics PV modules. The results of ANFIS training is shown in Figure 4. Having obtained the right Ireference value, output of ANFIS will be entered into the PI block to be compared with Ipv. After Ireference compared with Ipv, so error will produce and it will be forwarded to the block and generate PWM duty cycle value for switching on the SEPIC converter

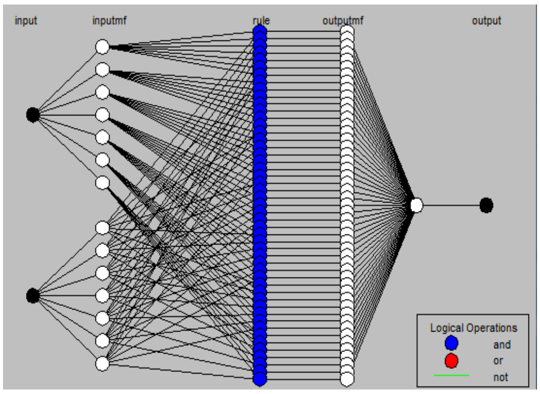

Figure 3. ANFIS controller Structure

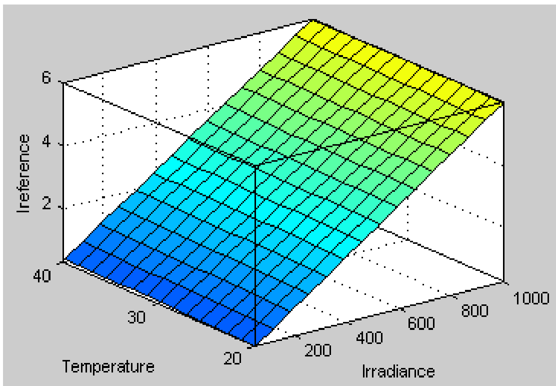

Figure 4. Surface between two inputs and one output

4. KY Inverse Converter Modeling

Bidirectional converter is a converter that is capable of raising and lowering the voltage in both directions. When bidirectional converter used to charging the energy storage, bidirectional converter operating on buck mode or lower the voltage. When bidirectional converter used to discharging the energy storage, bidirectional converter is operating on boost mode or raise the voltage. In this paper a bidirectional converter is used to store excess power generated by the PV modules into energy storage and power shortages when the PV modules to supply the load, the energy storage will help meet the need of PV modules in the power load. Bidirectional converter has two switches which are used to turn a buck or boost mode and change the direction of current flow charging and discharging of the energy storage. Bidirectional converter circuit is shown in Fig. 5. Bidirectional converter specification and design parameters is shown in Table 3. Equation (11) to (12) are used to modeling Bidirectional converter in Continous Conduction Mode [18, 19].

$$L = \frac{V_O(V_{DC}-V_O)}{\Delta I_L F_S V_{DC}} \quad (11)$$

$$C_{2(min)} = \frac{\Delta I_L}{8F_s \Delta V_o} \quad (12)$$

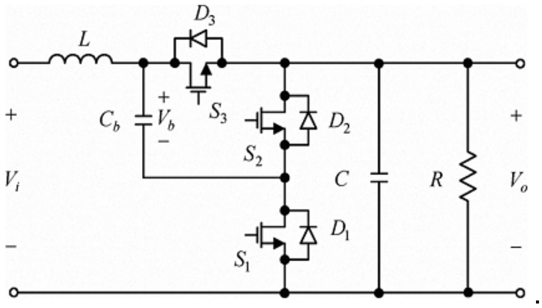

Figure 5. KY Inverse converter

Table 3. Bidirectional Converter Specification and Design Parameters

Parameter	Symbol	Value	Unit
DC link Voltage	*VDC*	400	V
Output voltage, battery side	*Vo*	240	V
Output voltage ripple	ΔV_o	5%	V
Switching Frequency	*fs*	40	KHz
Inductor current ripple	ΔI_L	5%	A
Inductance	*L*	6	mH
Capacitance 1	*C1*	200	uF
Capacitance 2	*C2*	200	uF

5. Inverter Modeling And Control

A single phase inverter has two arms and on each arm consists of two switch (IGBT). By using the techniques of control Pulse width modulated (PWM) dc bus voltage of 400 Vdc converted to 220VAC by adjusting the modulation index on the calculation of the inverter with the restrictions should not be more than one. This paper uses a single phase with frequency inverter 50 Hz, 220Vac. Specification and design parameters are shown in Table 4. Equation (13) to (15) are used to calculated value from modulation index [20].

$$V_o = m_a \frac{V_{DC}}{\sqrt{2}} \quad (13)$$

Equation (14) to (15) are used to calculated value from LC filter

$$L = \frac{X_L}{2\pi f_{res}} \quad (14)$$

$$C = \frac{1}{2\pi f_{res} X_C} \quad (15)$$

LC filters are used to filter harmonics, so the current or voltage waveform generated by the inverter becomes sinusoidal. LC filter is a filter that is commonly used in the inverter to reduce harmonics.

Table 4. Single Phase Inverter Specification And Design Parameters

Parameter	Symbol	Value	Unit
DC link Voltage	*VDC*	400	V
Ouput voltage	*VAC*	220	V
Switching Frequency	*fs*	10	KHz
Inductance Filter	*L*	1.36	mH
Capacitance Filter	*C*	6.37	uF

6. Simulation Result and Discussions

The simulation is performed using 10 PV module in series with total power output 2000W at 245V voltage. The energy storage using 20 battery at 12V 10Ah are series, so that the maximum power generated 2400W at 240V. The power at full load is 2000W. temperature input data as shown in Table 6. ANFIS method irradiance responses at 1000 W / m^2 is shown in Figure 6.

To test the ANFIS method in finding the maximum power point of testing the input data irradiance variations ranging from 50W / m^2 up to 1000W / m^2 is shown in Table 5. In addition, the test is also carried out with variations of when the PV modules power is greater than the power consumption of the load, the battery will be charging because the bidirectional of KY inverse converter is operating in buck mode.

Table 5. Variation Irradiance Effect

S (W / m2)	Pmax (Watt)	Ppv (Watt)	ANFIS (%)	Error
1000	2000	1998	99.90	0.001
950	1901	1899	99.89	0.001
900	1802	1800	99.89	0.001
850	1703	1701	99.88	0.001
800	1603	1601	99.88	0.001
750	1503	1500	99.80	0.002
700	1403	1400	99.79	0.002
650	1302	1300	99.85	0.002
600	1200	1196	99.67	0.003
550	1098	1094	99.64	0.004
500	997	994	99.70	0.003
450	895	892	99.66	0.003
400	793	790	99.62	0.004
350	690	688	99.71	0.003
300	588	583	99.15	0.009
250	486	482	99.18	0.008
200	385	381	98.96	0.008
150	284	282	99.30	0.007
100	185	183	98.92	0.011
50	89	87	97.75	0.011

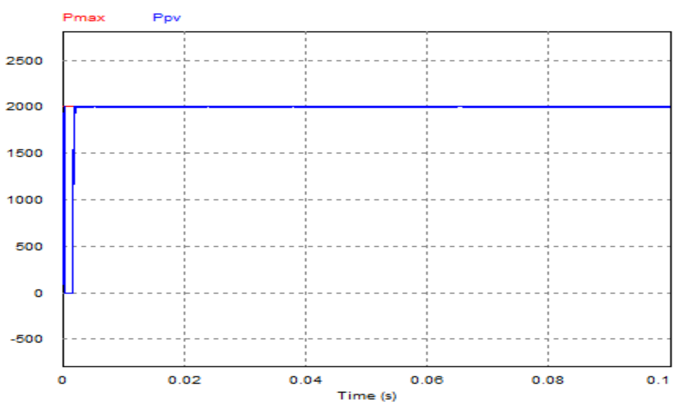

Figure 6. MPPT Responses using ANFIS

Table 6. Variation Temperature Effect

T(^{0}C)	Pmax (Watt)	Ppv (Watt)	ANFIS (%)	Error
40	1879	1877	99.89	0.001
39	1887	1885	99.89	0.001
38	1895	1893	99.89	0.001
37	1903	1901	99.89	0.001
36	1911	1910	99.95	0.001
35	1919	1917	99.90	0.001
34	1927	1925	99.90	0.001
33	1935	1934	99.95	0.001
32	1946	1942	99.79	0.002
31	1952	1950	99.90	0.001
30	1960	1958	99.90	0.001
29	1968	1965	99.85	0.002
28	1976	1974	99.90	0.001
27	1984	1982	99.90	0.001
26	1992	1990	99.90	0.001
25	2000	1998	99.90	0.001
24	2008	2006	99.90	0.001
23	2016	2014	99.90	0.001
22	2024	2022	99.90	0.001
21	2032	2030	99.90	0.001

When the PV power is less than the power consumed by the load, battery will be discharging because bidirectional converter is operating in boost mode. In this simulation SOC (State Of Charge) of the battery is 90% and gives a chance to look the charge and discharge process of the battery. Charging and discharging process is shown in Figure 7.

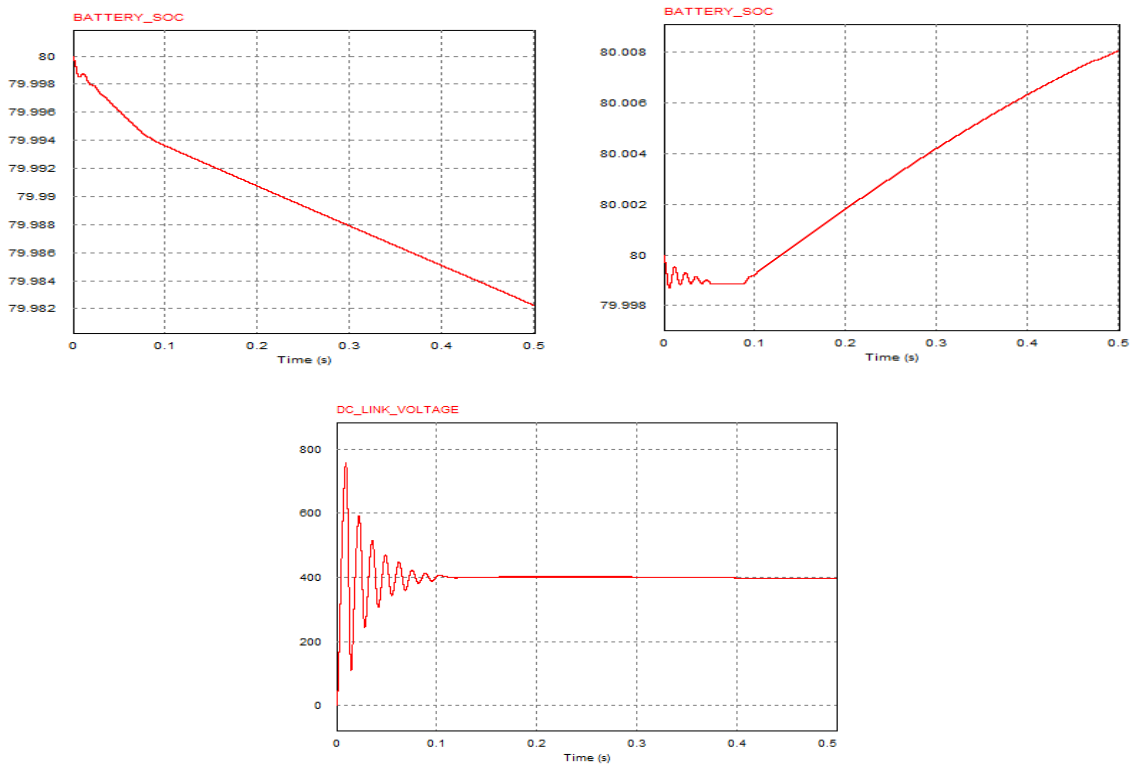

Figure 7. Charging, Discharging battery and DC Link Voltage

Tests on single phase inverter with a frequency of 10 KHz is by varying the load at 50% load and at full load, to see whether the generated voltage 220VAC is fixed in accordance with the results of the calculation of the index modulation. Testing with load variations to see the response inverter output current and voltage is shown in Figure 8.

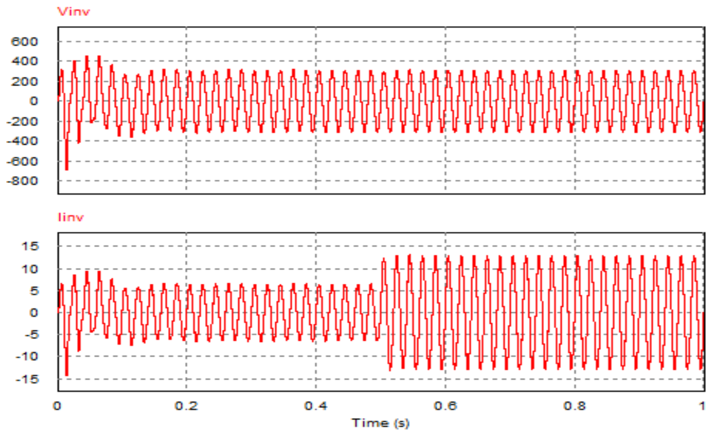

Figure 8. Voltage and current Inverter during variation load

7. Conclusion

Integrated subsystem MPPT-Bidirectional in a microgrid system has been presented. The simulation results show that the integration of the microgrid system is running properly. Maximization of the output power of PV module with ANFIS produces very high efficiency and stable on the irradiance variations and temperature. Charging and discharging process goes well and yielding the corresponding wave. The resulting DC voltage bus is also able to be maintained at a specified voltage. The inverter is able to maintain the output voltage with load variations.

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