Journal of Engineering and Applied Sciences 11 (11): 2353-2359, 2016
ISSN: 1816-949X

Wind-PV Hybrid System Modeling Using Bidirectional Converter with MPPT-Dual Adaptive Neuro Fuzzy Inference System (ANFIS) in Microgrid Isolated System

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Abstract: Photovoltaic (PV) and Wind Turbines (WT) are renewable energy sources that are very rapidly growing. A variety of operating systems and controls to maximize the output power of both renewable energy sources have become a problem that more and more research are performed today. Renewable energy sources are the right solution to overcome the problem of depleted fossil energy. However, when renewable energy sources have generated power to the limit and no longer been able to meet the load demand, energy storage will be required as a backup. This study discusses a microgrid distribution system to maximize the power output from PV and WT that are connected in parallel with the energy storage. Energy storage is used to store excess power generated by PV and WT and as a backup. In this study ANFIS method is used to maximize power generated by PV and WT with a maximum efficiency of 99.95% for PV and 99% for WT.

Key words: Photovoltaic, wind turbines, microgrid, ANFIS, backup

INTRODUCTION

Dwindling fossil energy led to many studies of substitute energy sources that can be renewed. Renewable energy source which is the most widely studied is the energy source of the sun. Research about the design, simulation and implementation of solar energy sources began widely studied (Esram and Chapman, 2007).

In addition to solar energy, wind energy sources also began widely studied, especially for application in remote areas that have strong wind conditions and relative constant. Wind energy sources become important for areas that have high wind potential. In remote areas, solar energy sources can also be developed and be combined with wind energy sources. Design and implementation of hybrid energy sources (wind and solar energy) are extensively explored and implemented recently (Kumar *et al*., 2015; Nair and Ebenezer, 2014).

Renewable energy sources require an energy storage system to store the excess power that generated by solar and wind energy. Energy storage can also help to replenish the shortage of power from renewable energy sources required by the load. The application of energy storage in microgrid systems has been widely implemented (Masood *et al*., 2014; Muoka *et al*., 2013a, b). Hybrid of solar and wind energy system can be further refined by utilizing a controller in order to maximize the output power of each renewable energy. In those hybrid systems, the method of tracking the maximum power point of the hybrid solar-wind power becomes crucial in order to get the maximum power on each renewable energy source.

The use of the method of Maximum Power point Tracking (MPPT) has been studied from the conventional method to artificial intelligence methods. Conventional methods for instance P and O and incremental conductance while artificial intelligence methods such as Neural Networks, Fuzzy and ANFIS (Murdianto *et al*., 2015; Muoka *et al*., 2013a, b; Iqbal *et al*., 2010; Mayssa and Sabita, 2012). Hybrid Solar-Wind energy has been widely used as a source which is connected to a microgrid distribution network (Bayir and Ozer, 2009; Adhikari *et al*., 2013; Joshi *et al*., 2014). This study discusses a WT-PV Hybrid System Modeling to maximize the power output from PV and WT using bidirectional converter with MPPT-Dual Adaptive Neuro Fuzzy Inference System (ANFIS) in microgrid isolated system (Fig. 1).

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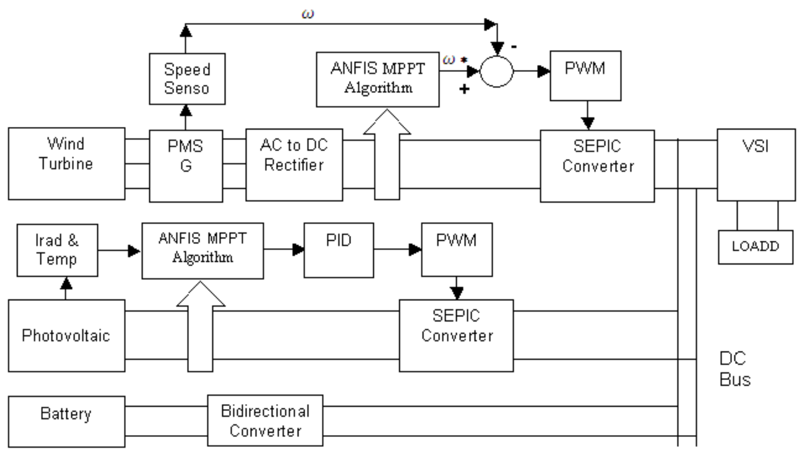

Fig. 1: Proposed system hybrid solar-wind

MATERIALS AND METHODS

In this study, a microgrid distribution system is simulated using 2 kW solar PV and 2 kW WT as the renewable energy sources. The (two) pieces 12 V, 100 AH batteries are used to store excess of power from PV and WT as a back-up energy, when the renewable energy sources are unable to meet the load demand.

ANFIS method is used to maximize the power generated by PV and WT. The 2 ANFIS based MPPT algorithms are developed, one for PV and the other for WT to maximize power generated by each renewable energy source. All sources will be combined and concentrated on a DC bus which would then be converted into AC by a single phase Voltage Source knverter (VSI). The AC inverter voltage is kept stable at 220 V AC to feed varying loads (Table 1).

Modeling of solar-PV array: The solar-PV array consists of a number of solar panels connected in series-parallel configuration and each panel consists of a number of cells. The power characteristic of the solar cell is formulated using its equivalent circuit. The equivalent circuit of the cell is composed of a current source in parallel with two diodes, series resistance and parallel resistance (Junsangsri and Lombardi, 2010). The output current of the equivalent circuit can be expressed as follows:

$$I_{pv} = I_{gen} - I_{si}\left[\exp\left(\frac{V_{pv}+I_{pv}R_1}{\frac{a.KT}{q}}\right)-1\right] \quad (1)$$

$$-Is_2\left[\exp\frac{\left(V_{pv}+I_{pv}R_1\right)}{\frac{a.KT}{q}}\right]-\frac{V_{pv}+I_{pv}R_1}{R_2}$$

Table 1: PV Panel Specifications (Solar, 2007)

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/°C
Temperature coefficient of Isc	(0.065 ± 0.015)%/°C
NOCT2	47±2°C

A 200 W panel is considered as consisting of 72 solar cells. Thus, output current of the panel is expressed as:

$$I_{pv} = n_p I_{gen} - n_p I_{s1}\left[\exp\left(\frac{\frac{V_{pv}}{n_s}+I_{pv}R_1}{a\frac{KT}{q}}-1\right)\right] \quad (2)$$

Where:

nP and nS = No. of cells connected in parallel and series
Ipv = Output current of the solar panel
Igen = Light generated current
Is1 and Is2 = Saturation currents through diodes
Vpv = Voltage at output of panel PV
R_1 = Series resistance of cell
R_2 = Parallel resistance
K = Boltzman's constant (1.38×10-23 JK^{-1})
T = Ambient temperature (K)
q = Charge constant (1.607×10-19 C)

Modeling of a wind turbine: The characteristic equation of a WT is modeled as shown in Eq. 3 which shows the capability of a WT to generate power (Hasanien and Muyeen, 2012). Wind speed of a WT is 8-10 m sec^{-1}. The wind speed determines the power output that can be generated by a WT and is expressed as follows:

$$P_t = \frac{1}{2} pAV_v{}^3 C_p \tag{3}$$

Where, the air density p is 1.22. The rotor area (A) is calculated as πr^2, i.e., 113.09 m^2. The value of power coefficient C_p is a function of blade angle (β) and tip speed ratio (λ) as follows :

$$C_p = 0.72\left(\frac{150}{\lambda} - 0.6\beta - 0.0028\,\beta^{2.14} - 13.2\right)e^{-18.4/\lambda} \tag{4}$$

Modeling of SEPIC (Single Ended Primary Inductance Converter) dc-dc converter: Sepic Converter is a dc to dc converter and is used to raise or lower its positive voltage polarity. This converter is the development of a buck-boost converter that has negative voltage polarity. In this study, the ANFIS algorithm is embedded to Sepic Converter so that Maximum Power Point Tracking can be realized and the PV is able to generate maximum power. Equation 5-9 are used for modeling Continuous Conduction Mode SEPIC (Muoka *et al*., 2012). SEPIC design specifications and parameters are shown in Table 2:

$$V_0 = V_{IN}\frac{D}{1-D} \tag{5}$$

$$L_1 = \frac{V_{IN}\times D}{\Delta i_{L1}\times f_s} \tag{6}$$

$$L_2 = \frac{V_{IN}\times D}{\Delta i_{L2}\times f_s} \tag{7}$$

$$C_0 = \frac{D}{R\times\frac{\Delta V_0}{V_0}\times f_s} \tag{8}$$

$$C_0 = \frac{D}{R\times\frac{\Delta Vc_s}{V_0}\times f_s} \tag{9}$$

To minimize the inductance value, it requires high switching frequency on Sepic converter. In this study, the switching frequency used for Sepic converter is 40 Khz. Bidirectional converter is used to store excess power from renewable energy sources so that the current flows from dc bus heading to energy storage. At the time when the renewable energy sources are no longer able to meet the load demand, the current flow changes from energy storage to the dc bus, therefore a bidirectional converter is needed which can divert the flow of current from two different directions.

Table 2 SEPIC specification and design parameters

Parameters	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_0	5%	V
Inductor 1	L1	9.8	mH
Inductor 2	L2	9.8	mH
Coupling capacitor	Cs	20	uH
Output capacitor	Co	20	uH

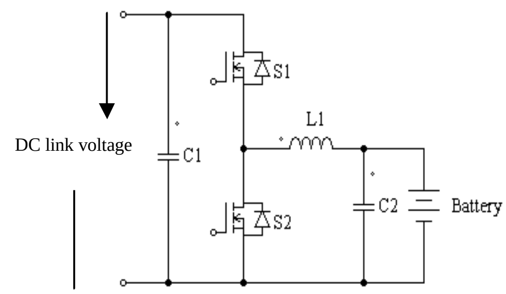

Fig. 2: Bidirectional DC-DC converter

Bidirectional converter circuit is shown in Fig. 2. Bidirectional converter specifications and design parameters are shown in Table 3. Equation 10 and 11 are used to model Bidirectional converter in Continous Conduction Mode (Hauke, 2011, 2010).

$$L = \frac{V_0\left(V_{DC} - V_0\right)}{\Delta I_L F_s V_{DC}} \tag{10}$$

$$C_{2(\min)} = \frac{\Delta I_L}{8F_s\Delta V_0} \tag{11}$$

Design and modeling of VSI: VSI feeds the consumer load through an LC filter. The unipolar PWM (Pulse Width Modulation) method is used for switching of power devices. The output of VSI in this case can be given as:

oVSI dc 5 8 V =+V ;in case of S =1,S =1 (12)

oVSI dc 6 7 V =-V ; in case of S =1,S =1 (13)

oVSI 5 7 V =0; in case of S =1,S =1 (14)

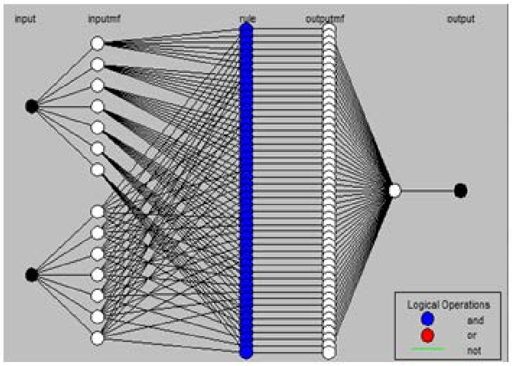

Fig. 3: ANFIS controller structure

Table 3: Bidirectional converter specifications and design parameters

Parameters	Symbol	Value	Unit
DC link voltage	VDC	400	V
Output voltage, battery side	Vo	240	V
Output voltage ripple	ΔV_0	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

$$oVSI\ 6\ 8\ V = 0;\ \text{in case of}\ S = 1, S = 1 \quad (15)$$

The VSI requires LC filter before feeding the load. For switching of power devices, unipolar PWM method is used. VSI is designed to feed 2 kW load at 220 V, 50 Hz. AC load with a frequency of 50 Hz requires Low Pass Filter (LPF) in the form of LC filter to cut high frequency harmonics before being transferred to the load. The VSI uses switching frequency of 10 kHz with an output frequency of 50 Hz. The resonance frequency for the filter is selected as 1 kHz which is high enough than cutout frequency and substantially lower than switching frequency, thus not to alter the low order harmonics and eliminate the higher order harmonics. The filter inductance is calculated considering the maximum voltage stress and its switching frequency (Kazmierkowski *et al*. 2002) as follows:

$$L_f = \frac{V_{dc} D_{imax}}{2f_{sVSI} \Delta L_f} \quad (16)$$

The value of Capacitance (Cf) is calculated using Eq. 13:

$$\omega_c = \frac{1}{2\pi\sqrt{L_f C_f}} \quad (17)$$

MPPT control strategy: The system uses ANFIS method for MPPT control on each renewable energy source. Approach using ANFIS method began to be used in the applications of MPPT. ANFIS method combines the advantages of Fuzzy and Neural Network. The proposed

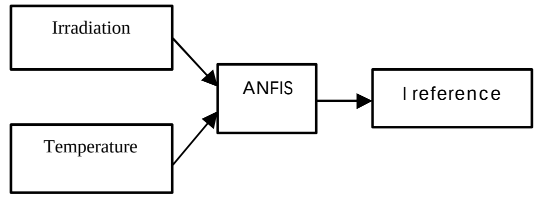

Fig. 4: ANFIS controller structure of PV

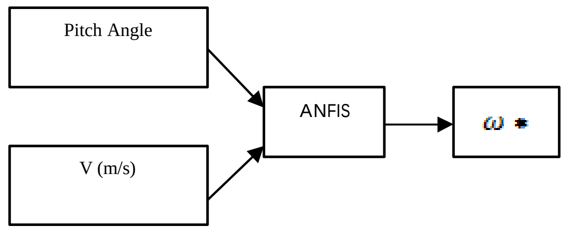

Fig. 5: ANFIS controller structure of wind turbine

method requires data of each renewable energy source for the process of learning. For PV, the required data are irradiance and temperature and for WT, the required data are pitch angle and speed as shown in Fig. 4 and 5. By using the proposed method, the power output from each renewable energy source can be maximized.

ANFIS method is a fuzzy method that is built using a neural network. ANFIS controller structure uses 2 inputs, 7 membership funtion, 49 rules and 1 output as shown in Fig. 3. This system has seven membership function in order to obtain accurate results and use logical operations AND. ANFIS algorithm in MPPT-PV uses two inputs, those are Irradiation and temperature and the output is reference current (I reference) as shown in Fig. 4. Irradiation and temperature data will be the basis for the process of learning the ANFIS algorithm in order to produce an accurate reference current. ANFIS algorithm in MPPT-WT uses two inputs, those are pitch angle and velocity and the output is reference rotor speed as shown in Fig. 5. Pitch angle and velocity data will be the basis for the process of learning the ANFIS algorithm in order to produce an accurate reference rotor speed.

RESULTS AND DISCUSSION

The simulation is performed on the state of the peak power that can be generated by PV and WT to see the performance of ANFIS algorithm to find the point of maximum power on both renewable energy sources. The simulation is also performed to see the output voltage of the inverter is still able to maintain stability when the PV and WT are connected to the system (hybrid mode) and the load varies as well. The response of ANFIS algorithm to find the maximum power point of a PV is shown in

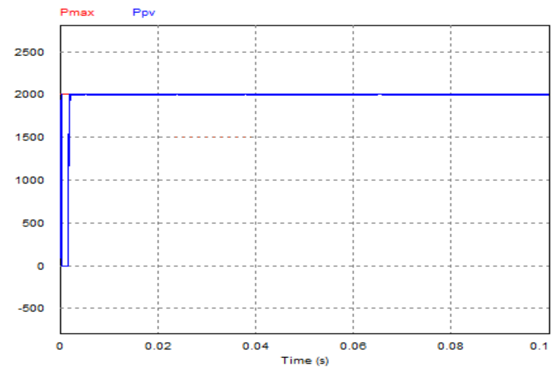

Fig. 6: MPPT-PV responses using ANFIS

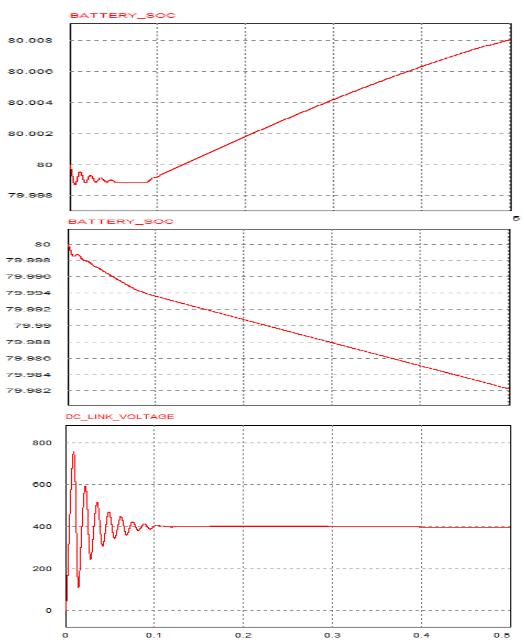

Fig. 7: Charging, discharging battery and DC link voltage

Fig. 6. The maximum power that can be generated by 2 kW PV by using ANFIS algorithm is very close to 2 kW (1990 W) with a fast time response.

The process of charging and discharging of the energy storage is governed by bidirectional dc-dc converter. At this simulation SOC (State Of Charge) in energy storage by 80%. Figure 7 shows the process of charging and discharging the energy storage. In general, the hybrid renewable of energy sources will produce instability in the DC bus. In this study, as shown in Fig. 6 the dc bus voltage is able to be kept stable at 400 V voltage so that, the voltage produced by the inverter is relatively stable too. The response of ANFIS algorithm to find the maximum power point of a WT is shown in Fig. 8. The maximum power that can be generated by 2 kW PV by

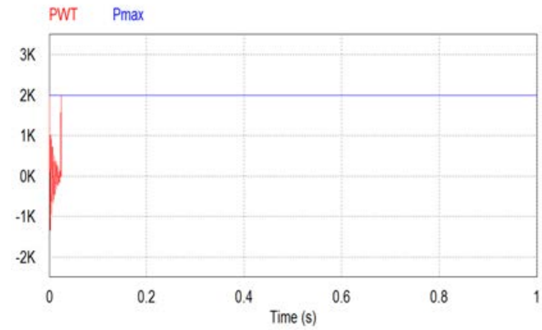

Fig. 8: MPPT wind turbines responses using ANFIS

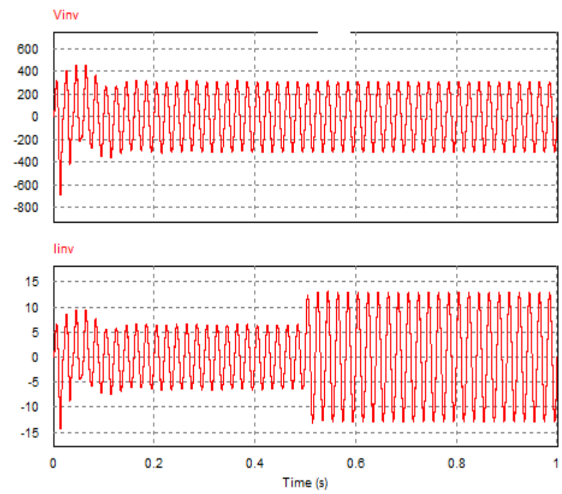

Fig. 9: Voltage and current Inverter during variation load

using ANFIS algorithm is very close to 2 kW (1980 W) with a fast response time. The main target of this system is the maximum power generated by both renewable energy sources (PV and WT) as well as the stability of the voltage at the output of the inverter when the load varies. Figure 9 shows that the voltage generated by the inverter to the load is able to be kept stable at 220V and is capable of maintaining stability of the voltage in the event of load changes.

CONCLUSION

Wind-PV Hybrid system has been integrated and simulated. Output power on each renewable energy source is successfully maximized using ANFIS method and is embedded in the SEPIC converter which functioned as MPPT. By using ANFIS method, very high accuracy (99.95% for PV and 99% for WT) and very fast response time to reach the maximum power point have been obtained. Bidirectional converter is able to overcome problems of charging and discharging of the energy storage. VSI is able to stabilize the voltage during load variations and sinusoidal waveform of VSI output is obtained by using LC filter.

ACKNOWLEDGEMENTS

The researchers gratefully acknowledge the support by INSINAS, research funded by Indonesian ministry of research and technology.

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