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Design and Implementation of Energy Management System with Fuzzy Control Using Sugeno Method

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ABSTRACT: In this project is used to improve the life cycle of battery and this method is based on mamdani method of fuzzy logic system.This paper present the design and implementation of energy management system using fuzzy control and then control of distribution power sources using MATLAB link.To improve the life cycle of battery fuzzy control manages the state of charge but instead of mamdani method,sugeno method is so much advantage because it is more compact and efficient.They also have adaptive techniques ie., it can be used to customize the membership function so that fuzzy system is best model of data.We can use the MATLAB command line function mam2sug to convert mamdani to sugeno constant output.The main advantages of sugeno type is more efficient work with optimization and adaptive technique guaranteed continuity of output surface suited to mathematical analysis.

KEYWORDS: Energy management system (EMS), fuzzy control, microgrid.

I.INTRODUCTION

A general power system uses battery energy storage to avoid a power outage or power surge caused by natural environmental factors. The design concept of this study was to increase the useful life of lithium batteries and to include charge and over discharge protection mechanisms.The proposed fuzzy control using sugeno type is to optimize energy distribution and to set up battery state of charge (SOC) parameters.

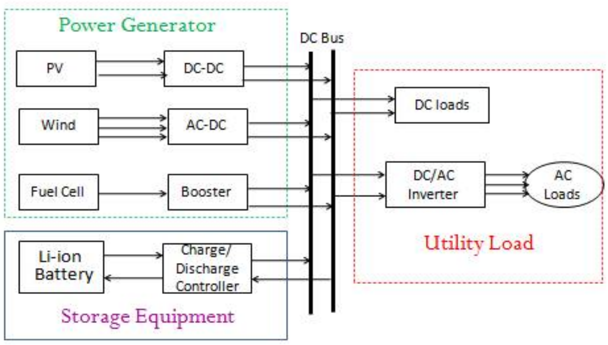

Fig 1.1:Block diagram of energy management system using fuzzy control

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II. MODELING OF GREEN ENERGY COMPONENTS

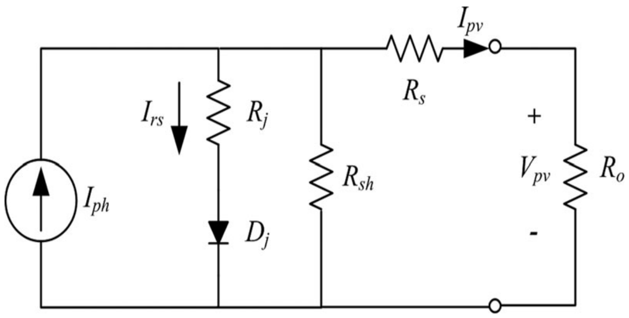

Fig 1.2: **Solar panel equivalent circuit**

To verify the accuracy of the designed controller, a dynamic model of the proposed micro grid system is necessary. The modeling of dc microgrid distributed energy and energy storage components was mainly built by MATLAB simulink mathematical modules, based on equivalent circuits of the components. The following describes the model of each subsystem in detail.

A. MODELING OF SOLAR CELL

Solar panel equivalent circuit is shown in Fig. 2.Solar panel current equation can be expressed by (1)–(3)

$$I_{pv} = n_p I_{ph} - n_p I_{rs}\left[\exp\left(\frac{q}{kTA}\frac{V_{pv}}{n_s}\right) - 1\right] \qquad (1)$$

where V_{pv} is output voltage of solar panels, I_{pv} is output current of solar panels, n_s is number of solar panels in series, n_p is number of solar panels in parallel, k is the Boltzmann constant (1.38×10^{-23} J/K), q is electron charge (1.6×10^{-19}C), A is ideality factor (1–2), T is surface temperature of the solar panels (K), and I_{rs} is reverse saturation current. In (1), the characteristic of reverse saturation current I_{rs} varies with temperature, as expressed by (2)

$$I_{rs} = I_{rr}\left[\frac{T}{T_r}\right]^3 \exp\left(\frac{qE_g}{kA}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right) \qquad (2)$$

where T_r is the reference temperature of the solar panels (K), I_{rr} is reverse saturation current of the solar panels at temperature T_r (K), and E_g is energy band gap of the semiconductor material

$$I_{ph} = [I_{scr} + \alpha(T - T_r)]\frac{S}{100} \qquad (3)$$

where I_{scr} is the short-circuit current at reference temperature T_r and illumination intensity 1 kW/m^2 , α is the short-circuit current temperature coefficient of the solar panels, and *S*is the illumination intensity (kW/m^2). This study used Sharp NUS0E3E solar modules, each with a power rating of 180 W, as the photovoltaic device of the microgrid system. This study used a solar 5 kW power system, generated by two photovoltaic arrays in parallel, where each arraywas built with 14 solar panels in series. The simulated output power versus output voltage of the solar cell is shown in Fig. 3. This study used constant illumination intensity 1 kW/m^{2}and constant temperature with varying V_{pv} for simulation verification.

B. WIND TURBINE MODELING

The power generated by wind turbine is expressed as where P_W is power generated by the wind turbine *W*, *P* is density of gas in the atmosphere (kg/m), *A* is cross-sectional area of a wind turbine blade m^2 , *V* is wind velocity (m/sec), and C_p is the wind turbine energy conversion coefficient.

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$$P_W = 0.5\rho A V^3 C_P(\lambda, \theta) \qquad (4)$$

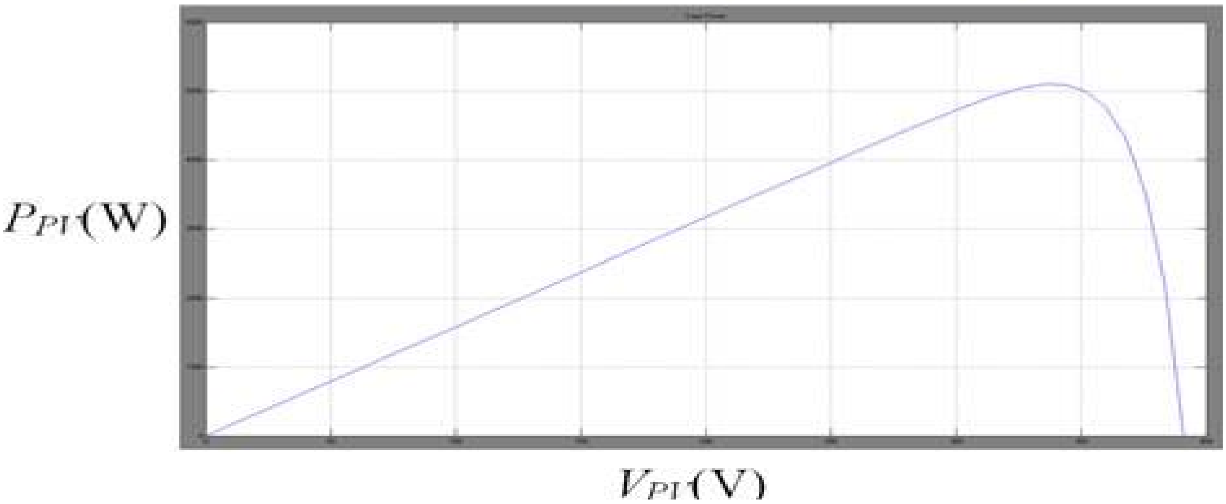

Fig 1.3*:* **Simulated output power** ***P*****PV versus output voltage** ***V*****PV of the solar cell with constant illumination intensity 1 kW/m2 .**

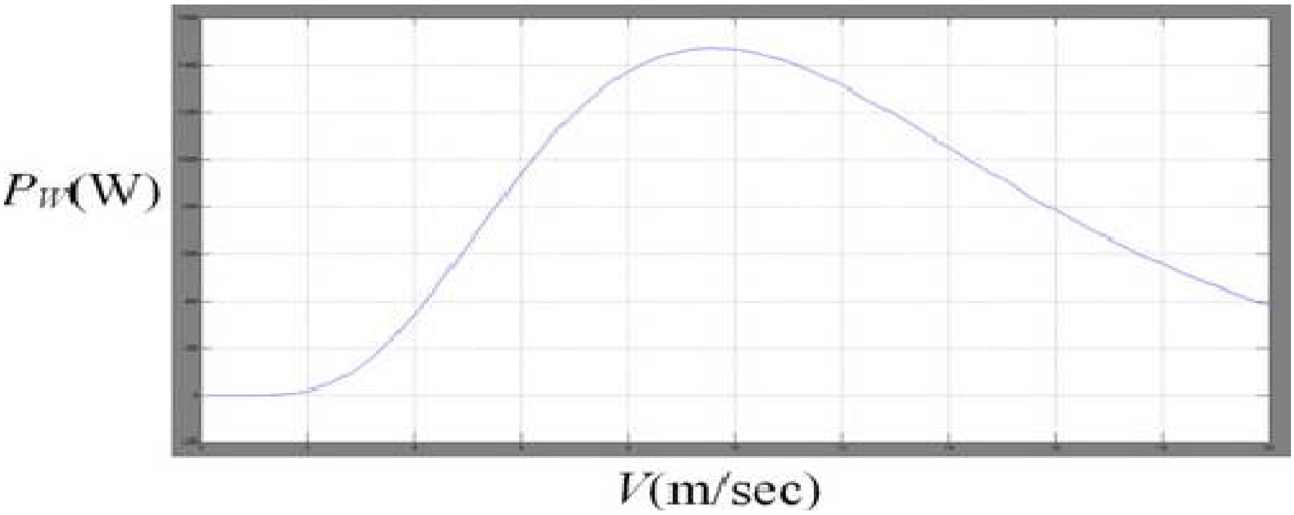

Fig 1.4: Simulated output power ***PW*** **with various wind speeds** ***V***

The density of gas ρ and energy conversion coefficient C_P in (4) is expressed by (5) and (6), respectively

$$\rho = \left(\frac{353.05}{T}\right) \exp^{-0.034\left(\frac{Z}{T}\right)} \qquad (5)$$

$$C_p(\lambda, \theta) = \left(\frac{116}{\lambda_i} - 0.4 * \theta - 5\right) \cdot 0.5 \exp^{\frac{-16.5}{\lambda_i}} \qquad (6)$$

where Z is the altitude, T is the atmospheric temperature, λ_i is the tip speed ratio, and θ is the blade tilt angle. Equation (7) gives the expression of the tip speed ratio λ_i in (6) and (8) is the expression of the initial tip speed ratio λ in (7)

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$$\lambda_i = \frac{1}{1/(\lambda + 0.089\theta) - 0.035/(\theta^3 + 1)} \qquad (7)$$

$$\lambda = r\frac{\omega}{V}. \qquad (8)$$

The wind turbine used in this studywasAWV-1500 of Gallant Precision Machining Company, Ltd. Wind speed is the most critical factor in wind power generation. This simulated output power *Pw* of the wind turbine with various wind speeds *V* .

C. LITHIUM-ION BATTERY MODELING

Eq. (9) is the discharge equation and (10) the charge equation of the lithium-ion battery

$$f_1(it\ i^*i) = E_0 - K \cdot \frac{Q}{Q - it} \cdot i^* - K \cdot \frac{Q}{Q - it} \cdot it + A \cdot \exp(-B \cdot it) \qquad (9)$$

D. FUEL CELL MODELING

Fuel cells provide a high efficiency clean alternative to today’s power generation technologies. The polymer electrolyte membrane (PEM) fuel cell has gained some acceptance in medium power commercial applications such as creating backup power, grid tied distributed generation, and electric vehicles [1]. The output voltage *E* of the PEM fuel cell is represented as

III. INTELLIGENT ENERGY MANAGEMENT SYSTEM

As shown in Fig. 1, the system configuration of the proposed dc microgrid system includes five major blocks. To design an accurate controller of the proposed microsystem, the dynamic mathematical models of the power sources (PV, wind turbine, and fuel cell), dc/dc converters (buck-boost, buck, and phaseshifted full-bridge converters), bidirectional converter (symmetrical full-bridge converter), and bidirectional inverter (fullbridge inverter) of the integrated micro-system are necessary.However, the modeling, analysis, and design of the proposed integrated dc microsystem are not simple. To maintain the battery SOC with EMS, the fuzzy controller is needed to meet design specifications, because the control for EMS is a low response component and the models of dc/dc converters, dc/ac converters of themicro-dcmicrogrid system are unnecessary. Additionally, the dc microsystem is a nonlinear system and fuzzy logic can offer a practical way for designing nonlinear control systems. Fuzzy control theory is designed and implemented in EMS for the dc microgrid system to achieve the optimization of the system. The design criterion requires that both the photovoltaic device and the wind turbine are supplied by a maximum power point tracker to maintain the maximum operating point. The difference between actual load and total generated power is taken into account for Li-ion battery in charge and discharge modes. The life cycle and SOC of the battery are in direct proportion. To improve the life of the Li-ion battery, we can control and maintain the SOC of battery with fuzzy control.

A. FUZZY CONTROL

Fuzzy theory was first proposed in 1965 by Lotfi. A. Zadeh,an American scholar of automatic control, as a tool of quantitative expression for concepts that could not be clearly defined. A fuzzy control system is based on fuzzy-logic thinking in the design of how a controller works. The so-called fuzzy logic is to establish a buffer zone between the traditional zero and one, with logic segments of none-zero and none-one possible. It allows a wider and more flexible space in logic deduction for the expression of conceptual ideas and experience. A fuzzy controller differs from a traditional controller in that it employs a set of qualitative rules defined by semantic descriptions [38]–[40]. The fuzzy controller is applied in the proposed microgrid power supply system, as shown in Fig. 7. To obtain the desired SOC value, the fuzzy controller is designed to be in charging mode or discharging mode for the proposed microgrid system. The input variables of the fuzzy control are ΔSOC and Δ*P* and output variable is Δ*I*. The definition of input and output variables are listed as follows:

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$$\Delta SOC = SOC_{command} - SOC_{now}$$
$$\Delta P = P_L - (P_{wind} + P_{pv}).$$

The control rules of this study prioritize selling additional electricity generated by the renewable energy in response to the present control strategy of microgrid development for selling electricity and increasing the life of Li-ion batteries. Table I shows the fuzzy rules of the proposed system. For example, the output variable ΔI is PB (the degree of discharging current is large) when the input variable ΔP is NB (the amount of electricity to sell is large) and input variable ΔSOC is NS (greater than the SOC command and the membership degree is small). However, the output variable ΔI is NS (the degree of charging current is small) when the input variable ΔP is NB (the amount of electricity to sell is large) and input variable ΔSOC is PS (smaller than the SOC command and the membership degree is small). The output variable is NS instead of NB when the system is operated in the above \ conditions because selling electricity is the first priority in this case. Thus, the fuzzy control table of the proposed dc microgrid system is not symmetrical. To extend the life of storage batteries in the design of fuzzy control, the fuzzy control rules are set to maintain battery SOC above 50%. Moreover, in the fuzzy control rules the Li-ion battery is forced to discharge as the control strategy when power demand at load was greater than the power generated by the renewable energy.

B. ILLUSTRATION EXAMPLE

The dynamic model of the proposed dc microgrid system usingMATLAB simulink is shown in Fig. 10, where the system consists of a 5 kW solar module, a 1.5 kW wind turbine module, a 1.5 kW Li-ion battery module, and a 6.5 kW load. This example verifies the accuracy of the proposed system with fuzzy controller that can maintain the SOC of the battery at a certain level whether initial value of the SOC is low or high. As shown in Fig. 11, the fuzzy controller Li-ion battery SOC is maintained at 50% with an initial value of 10%. As shown in Fig. 12, the fuzzy controller Li-ion battery SOC is maintained at 50% with an initial value of 90%.

To control strategy of this study is to sell electricity as a priority and to maintain battery SOC. Fig. 13 shows that the,fuzzy controller forced the Li-ion battery to discharge when ΔP was greater than 5 kW to keep the system in power equilibrium without going over the power rating of the bidirectional inverter subsystem. However, the SOC of the battery is not the first priority to achieve the safety when the inverter is over the power rating.

Fig 1.5: TABLE I
FUZZY CONTROL RULES

ΔI		ΔP				
		NB	NS	ZO	PS	PB
ΔSOC	NB	PB	PB	PB	PB	PB
	NS	PB	PB	PS	PS	PB
	ZO	ZO	ZO	ZO	PS	PB
	PS	NS	NS	NS	NS	PB
	PB	NB	NB	NB	NB	PB

This example verifies the accuracy of the proposed systemwith fuzzy controller that can maintain the SOC of the battery at a certain level whether initial value of the SOC is low or high. As shown in Fig. 11, the fuzzy controller Li-ion battery SOC is maintained at 50% with an initial value of 10%. As shown in Fig. 12, the fuzzy controller Li-ion battery SOC is maintained at 50% with an initial value of 90%. To control strategy of this study is to sell electricity as a priority and to maintain battery SOC. Fig. 13 shows that the fuzzy controller forced the Li-ion battery to discharge whenΔP was greater than 5 kW to keep the system in power equilibrium without going over the power rating of the bidirectional inverter subsystem. However, the SOC of the battery is not the first priority to achieve the safety when the inverter is over the power rating.

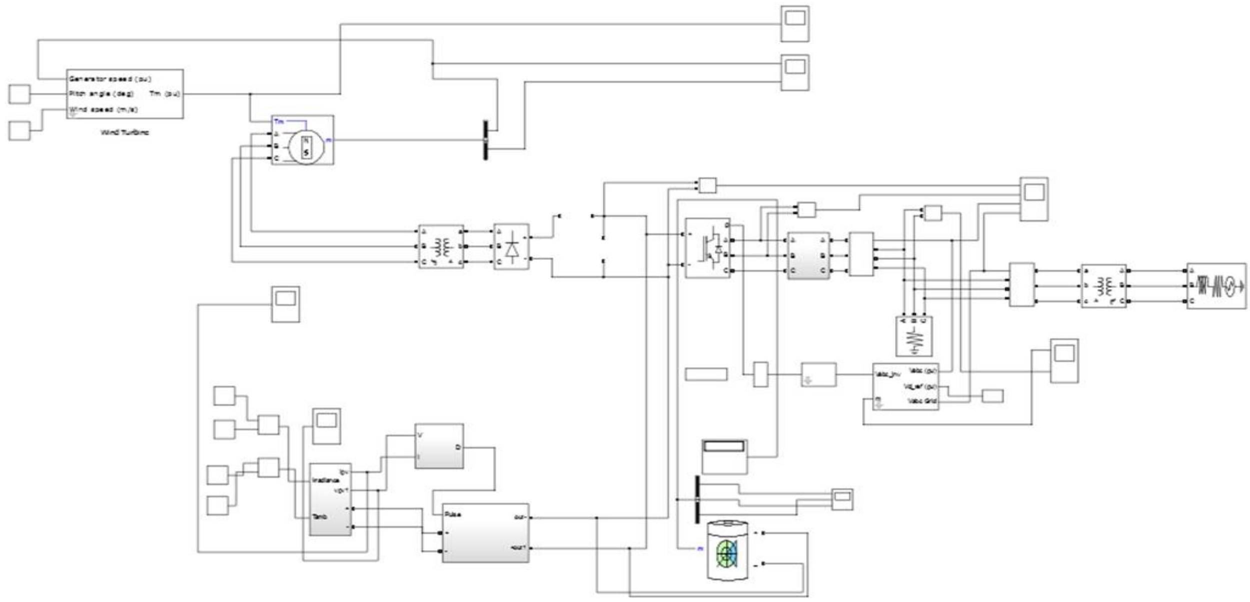

Fig 1.6: Fuzzy control of energy management system using MATLAB simulink

IV. CONCLUSION

This paper presents the modeling, analysis, and design fuzzy control using sugeno method to achieve optimization of an energy management system for a dc microgrid system. From the simulation results, the system achieves power equilibrium, and the battery SOC maintains the desired value for extension of battery life by using the control rules for a dc microgrid. Additionally, the optimization rules can be included in the intelligent microgrid management system, and the system can conduct data communication and control operating status of subsystems via the RS-485/ZigBee network. The management system takes advantage of the design to control microgrid with power equilibrium, and achieves optimal control of the dc microgrid system.

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