

Figure 5: Simulation results of battery with constant discharge of 5 A

This study simulated with constant discharge of 5 A for Validation and observation of SOC variation is shown in Figure 5. The battery voltage is easy to measure and implement in the circuit. From the simulated results, we can see the nonlinearity between voltage and SOC of the Li-ion battery. Therefore, the SOC parameter of batteries has been selected as the design factor instead of battery voltage in this paper.

2.4 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. The output voltage E of the PEM fuel cell is represented as

$$E = E_n - (-V_{act} + V_{ohm} + V_{con}) \quad (12)$$

Where E_n is Nernst voltage, V_{act} is the activation over potential, V_{ohm} is ohmic over potential, and V_{con} is concentration over potential.

$$V_{act} = -\left[\xi_1 + \xi_2 T + \xi_3 T \ln(Co_2) + \xi_4 T \ln(i_f) \right] \quad (13)$$

$$V_{ohm} = i_f R_M \quad (14)$$

$$R_M = \frac{18.6 \left[1 + 0.03 \left(\frac{i_f}{A_f} \right) + 0.062 \left(\frac{T}{303} \right)^2 \left(\frac{i_f}{A_f} \right)^{2.5} \right] l_1}{\left[\lambda_1 - 0.634 - 3 \left(i_f / A_f \right) \right] \exp \left[4.18 \left(\frac{T-303}{T} \right) \right] A_f} \quad (15)$$

$$V_{con} = -B_0 \cdot \ln \left(1 - \frac{J}{J_{max}} \right) \quad (16)$$

where T is operating absolute temperature, Co_2 is concentration of oxygen, i_f is output current of the fuel cell, $\xi_{1,2,3,4}$ are reference coefficients, l_1 is effective thickness of membrane, λ_1 is adjustable coefficient, A_f is effective area, B_0 is operating constant, J is current density, and J_{max} is maximum current density. The simulated output voltage with constant discharge of 10A is shown in Figure 6.

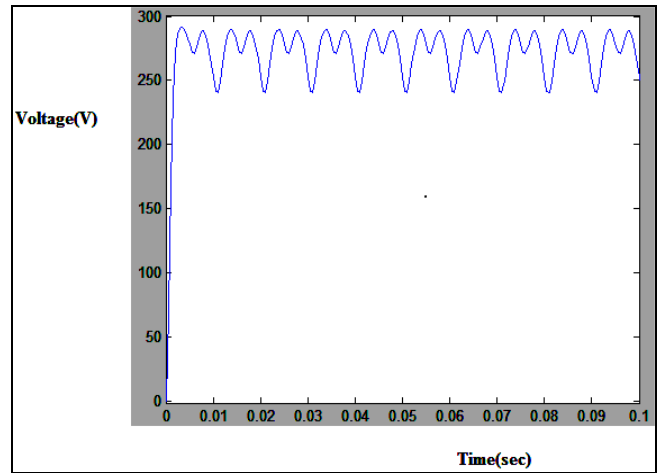


Figure 6: Simulated voltage of fuel cell with a constant discharge of 10 A

3. Energy Management System

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 need to control and maintain the SOC of battery with fuzzy control. The dc micro system is a nonlinear system and fuzzy logic can offer a practical way for designing nonlinear control systems.

3.1 Fuzzy control

The fuzzy controller is applied in the proposed microgrid power supply system, as shown in Figure 7.

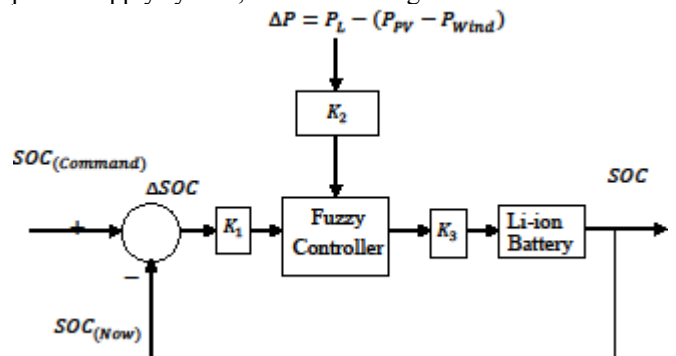


Figure 7: Block diagram of fuzzy control to maintain SOC of the battery

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 ΔP and output variable is ΔI . The definition of input and output variables are listed as follows:

$$\Delta SOC = SOC_{command} - SOC_{now} \quad (17)$$

$$\Delta P = P_L - (P_{wind} + P_{pv}) \quad (18)$$

Where ΔP is the power difference between required power load (PL) and sum of the powers coming from solar (Ppv) and wind sources (Pw).

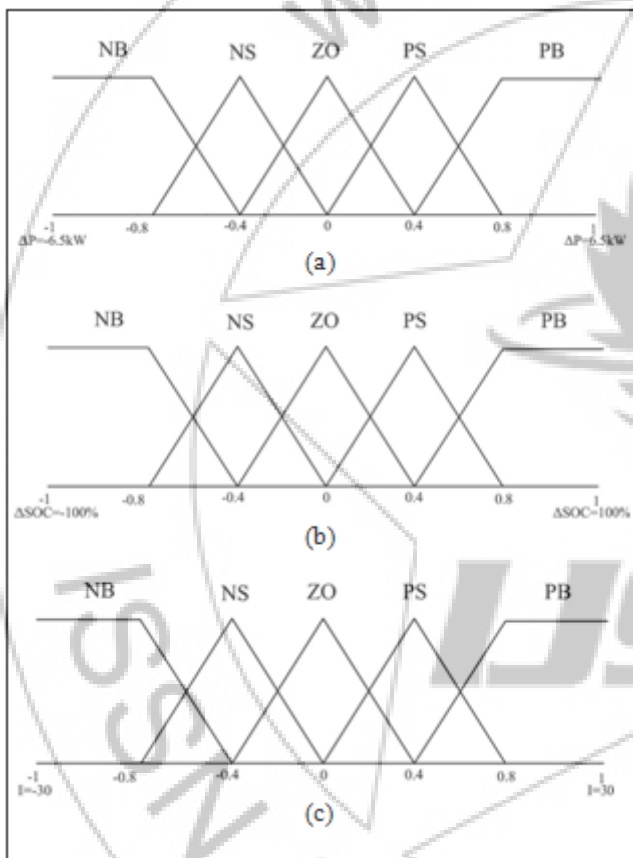
The input and output membership functions of fuzzy control contain five grades: NB (negative big), NS (negative small), ZO (zero), PS (positive small), and PB (positive big), as shown in Figure 8. Through scaling factors K1 and K2, we can determine the membership grade and to obtain the output current ΔI for charge and discharge variance of the Li-ion battery. If the ΔP is negative, it means that the renewable energy does not provide sufficient energy needed for the load, the battery must be operated in charging mode; if the ΔSOC is negative, it means that the SOC of the battery is greater than the demand SOC. Thus, the battery must operate in discharge mode.

Figure 8: Input membership functions of variables (a) ΔP (b) ΔSOC and (c) ΔI

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 1, shows the fuzzy rules of the proposed system.

Table 1: Fuzzy Control Rules

		ΔP				
		NB	NS	ZO	PS	PB
ΔI	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



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.

3.2 Implementation of Energy Management System

The proposed fuzzy EMS was implemented using LabVIEW graphic software to control and monitor the DC Microgrid system with three power sources: solar cell, wind turbine and fuel cell. The simulated data from each subsystem is integrated into the fuzzy logic using fuzzy rules of Labview is shown in Figure 9.

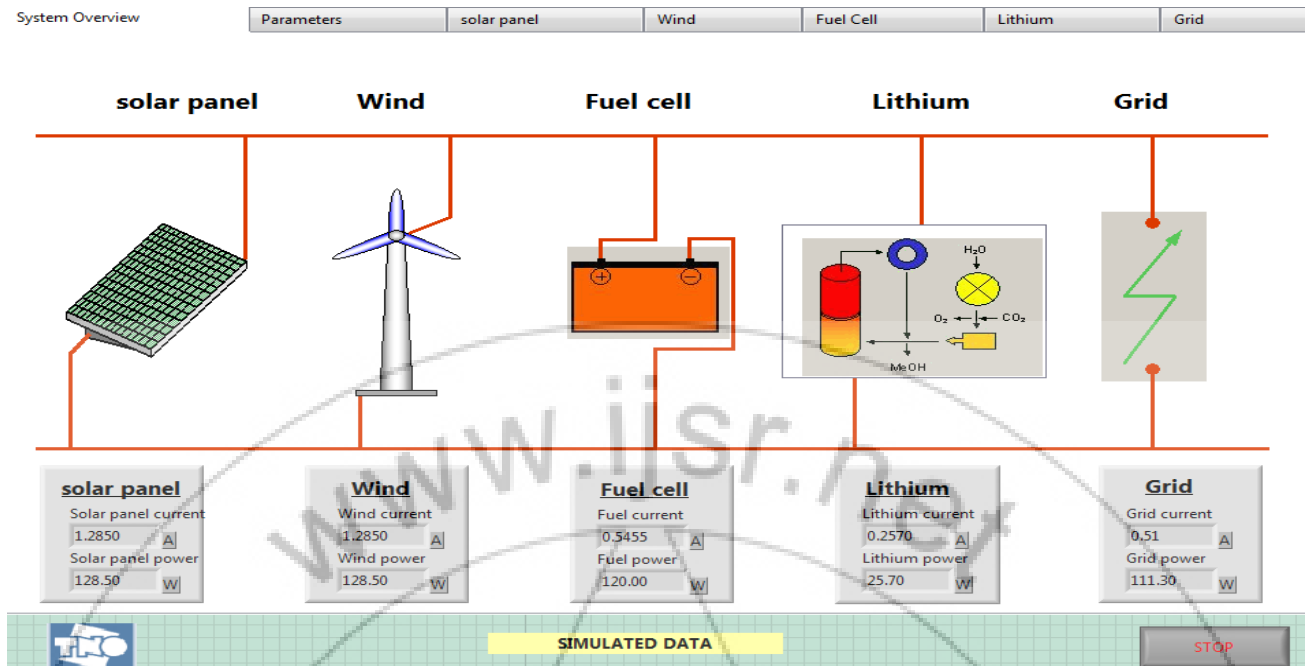


Figure 9: EMS showing the integrated testing of the proposed Dc microgrid system in Labview

4. Conclusion and Future Scope

This paper presents the design, Modelling and analysis of Fuzzy control to achieve optimization of an Energy management system for a dc microgrid system. From the simulation results, the battery SOC maintains the desired value for extension of battery life and the system achieves power equilibrium by using the control rules for a dc microgrid.

Additionally, the optimization rules can be included in the intelligent microgrid management system, so that the system can conduct data communication and control operating status of subsystems via the RS-485/ZigBee network. The Energy 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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