Energy Management System Implementation for A DC Micro Grid System Using Fuzzy Control

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Abstract: ***This paper implements the Energy management system for dc microgrid. In this Design, Analysis and control of power sources are made with Matlab/Simulink and Integration of these models in labview has been done. The Microgrid contains a solar panel, wind turbine, lithium ion battery and the fuel cell for continuous supply of power to the grid. For the improvement of battery life and its usage, state of charge has been introduced and its desired state is managed by fuzzy control of Labview.***

Keywords: Energy Management System (EMS), Microgrid, Fuzzy Control, State Of Charge (SOC), Fuzzy Control Rules.

1. Introduction

The awareness about power generation through conventional resources leads to Environmental damage as well as depletion in the tradition resources. Now–a –days the necessity of Renewable energy resources has been grownup for energy development. Currently the green energy used in power generation includes: wind, thermal, biomass, solar and tidal. By the year 2020, a large number of countries set a goal of increasing the usage of renewable energy above 20% of their total power consumption. Also the distributed power generation systems will have significant effects in environmental factors. In general power systems batteries are the energy storage sources used to avoid power outage or power surges caused due to environmental factors.

The Present trend of renewable energy development is a combination of distributed power sources and energy storage subsystems to form a micro-grid by which energy loss in power transmission lines over long distances is reduced. This energy is converted into dc and buffered with energy storage elements and then inverted to ac and fed into the utility grid.

In this development of the renewable energy sources a control method is required to optimize energy distribution of a micro-grid system. Therefore, in this construction several models have been used like solar power, wind power generation, lithium-ion battery fuel cell and Dc load. Figure 1 shows the dc micro-grid system in this study, the power generator typically includes solar panels, wind turbines and fuel cells.

The base power to emergency loads is provided by the fuel cell during a power failure. The maximum power drawn from the solar panels and the wind turbines are fed to the grid. Under power failure the first discharged power source is the lithium ion battery. If time limit increases the fuel cell starts supplying the power. Here the grid voltage regulation is operated by the battery discharger. The battery can be charged and depending on its state of charge (soc), which can be operated by means of Energy management system (EMS).

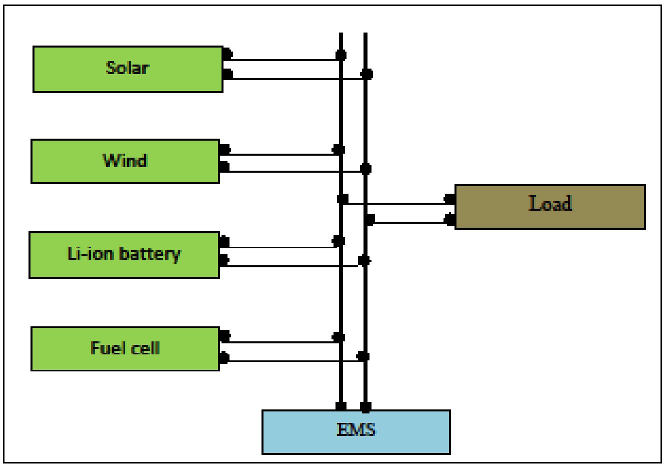

Figure1: configuration of DC microgrid system

2. Modeling of MicroGird Components

Dc micro grid input components can be modeled by making use of MATLAB/Simulink. Thus mathematical models are built for each component as following

2.1 Solar Cell Modeling

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

$$I_{pv} = n_p I_{ph} - n_p I_{rs}\left[\exp\left(\frac{qV_{pv}}{kTAn_s}\right) - 1\right] \qquad (1)$$

where Vpv is solar panels output voltage, Ipv is solar panels output current, ns is number of solar panels in series, np is number of solar panels in parallel, k is Boltzmann constant (1.38 × 10−23 J/K), q is one electron charge (1.6 ×10−19C), A is ideality factor (1–2), T is the surface temperature of the solar panels (K), and Irs as reverse saturation current. The characteristic is reverse saturation current Irs varies with temperature.

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

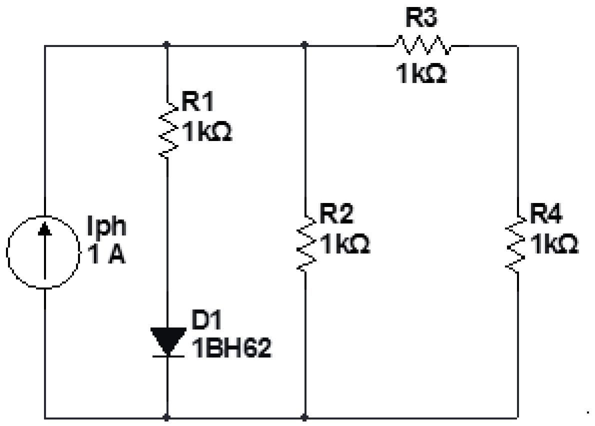

Figure 2: Solar panel equivalent circuit

Where Tr is reference temperature of the solar panels (K), Irr is the reverse saturation current of the solar panels at temperature Tr (K), and Eg is energy band gap of the semiconductor material

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

Where Iscr is the short-circuit current at reference temperature Tr and illumination intensity 1 kW/m2 , α is the short-circuit current temperature coefficient of solar panels, and S is illumination intensity (kW/m2). In this study used Sharp NUS0E3E solar modules, each one is a power rating of 180 W, as photovoltaic device of Microgrid system.

This study used solar 5 kW power system, generated by 2. Photovoltaic arrays in parallel, where each array was built with 14 solar panels in series. The simulated output is solar cell is shown in figure 3.

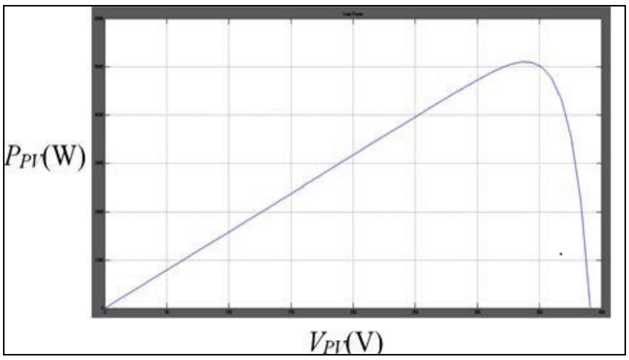

Figure 3: Simulated output power PPV versus output voltage VPV of the solar cell

This study is used constant illumination intensity 1 kW/m2 and a constant temperature with a varying Vpv for simulation verification.

2.2 Wind Turbine Modeling

The power generated by wind turbine is expressed as

$$P_w = 0.5\rho A V^3 C_p\left(\lambda, \theta\right) \qquad (4)$$

Where Pw 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 m2 , V is wind velocity (m/sec), and Cp is the wind turbine energy conversion coefficient. The density of gas ρ and energy conversion coefficient Cp in (4) is expressed by (5) and (6), respectively

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

$$C_P\left(\lambda, \theta\right) = \left(\frac{116}{\lambda_i} - 0.4 * \theta - 5\right) 0.5 exp^{-16.5/\lambda_1} \qquad (6)$$

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

$$\lambda_i = 1 / \left(\frac{1}{\lambda + 0089\theta} - 0.035 / \left(\theta^3 + 1\right)\right) \qquad (7)$$

$$\lambda = r\left(\omega / V\right) \qquad (8)$$

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.The simulated output of wind Turbine is shown in Figure 4.

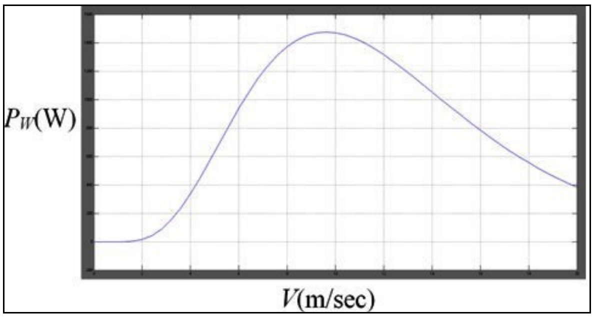

Figure 4: Simulated output power Pw with various wind speeds V

2.3 Lithium - Ion Battery Modeling

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

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

$$f_2\left(it\, i^* i\right) = E_0 - \left(K + \left(\frac{Q}{Q + 0.1Q}\right) + it\right) + it + A + \exp\left(-B + it\right) \qquad (10)$$

Where E0 is initial voltage (V), K is polarization resistance

(Ω), i* is low-frequency dynamic current (A), i is battery current (A), it is the battery extraction capacity (Ah), Q is maximum battery capacity (Ah), A is exponential voltage (V), B is exponential capacity (Ah)-1 .SOC of the battery is an important factor, which is calculated by

$$SOC = 100\left(1 - \int_0^t i.dt \;/ Q\right) \qquad (11)$$

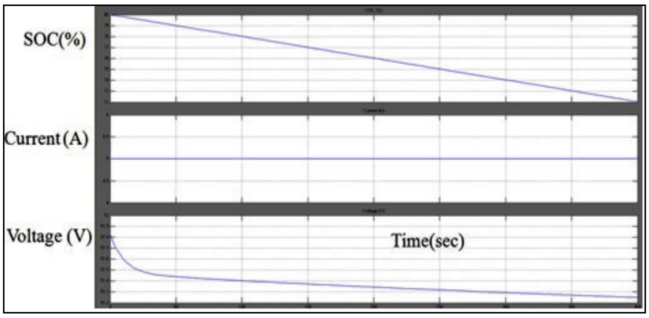

Figure 5: Simulation results of battery with constant discharge of 5 A

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

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

Where En is Nernst voltage, Vact is the activation over potential, Vohm is ohmic over potential, and Vcon is concentration over potential.

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

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

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

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

where T is operating absolute temperature, Co2 is concentration of oxygen, if is output current of the fuel cell, ξ1,2,3,4 are reference coefficients, l1 is effective thickness of membrane, λ1is adjustable coefficient, Af is effective area, B0 is operating constant, J is current density, and Jmax is maximum current density. The simulated output voltage with constant discharge of 10A is shown in Figure 6.

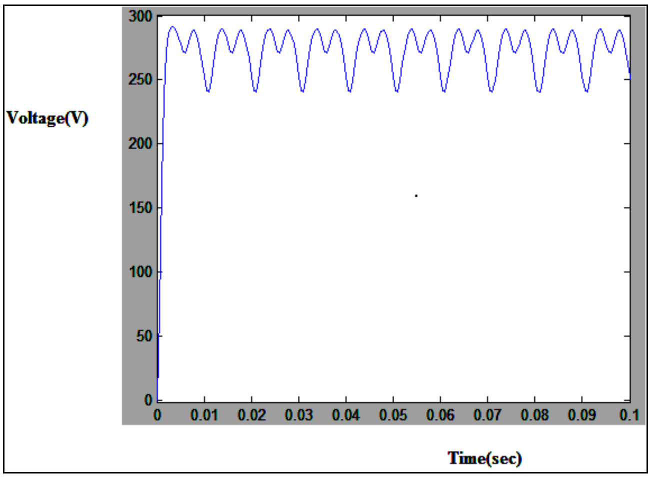

Figure 6: Simulated voltage of fuel cell with a constant discharge of 10 A

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.

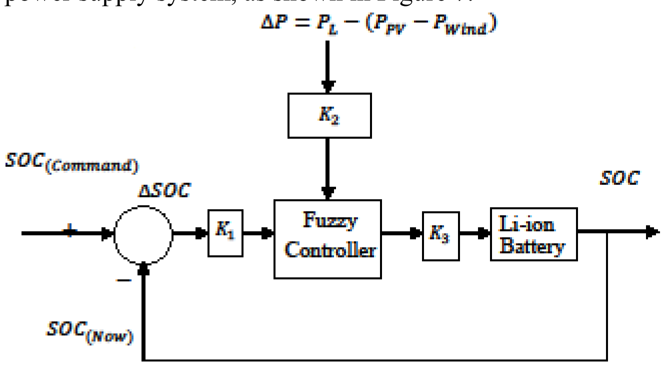

Figure 7: Block diagram of fuzzy control to maintain SOC of the battery

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 Δ*P* and output variable is Δ*I*. The definition of input and output variables are listed as follows:

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

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

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 Δ*I* for charge and discharge variance of the Li-ion battery. If the Δ*P* 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.

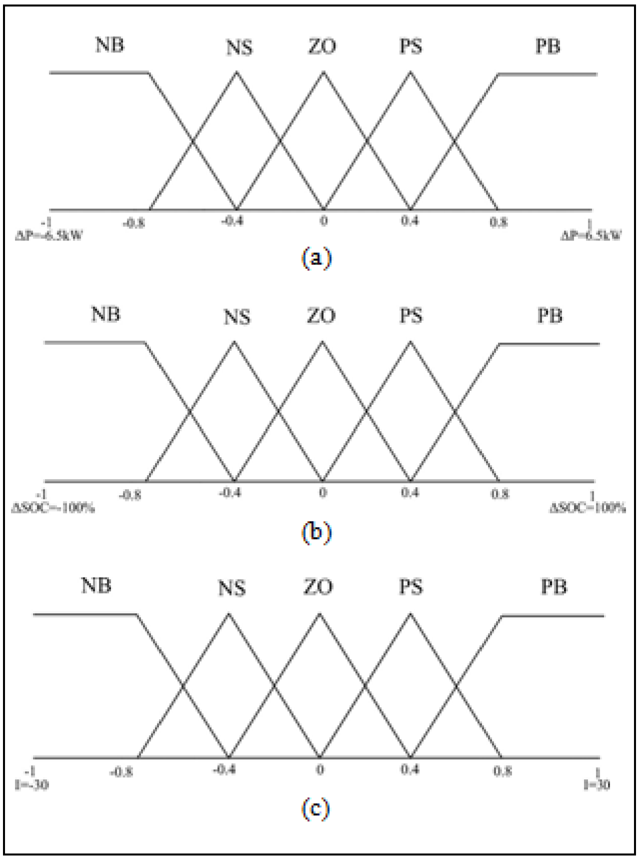

Figure 8: Input membership functions of variables (a) ΔP (b) ΔSOC and (c) ΔI

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

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

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.

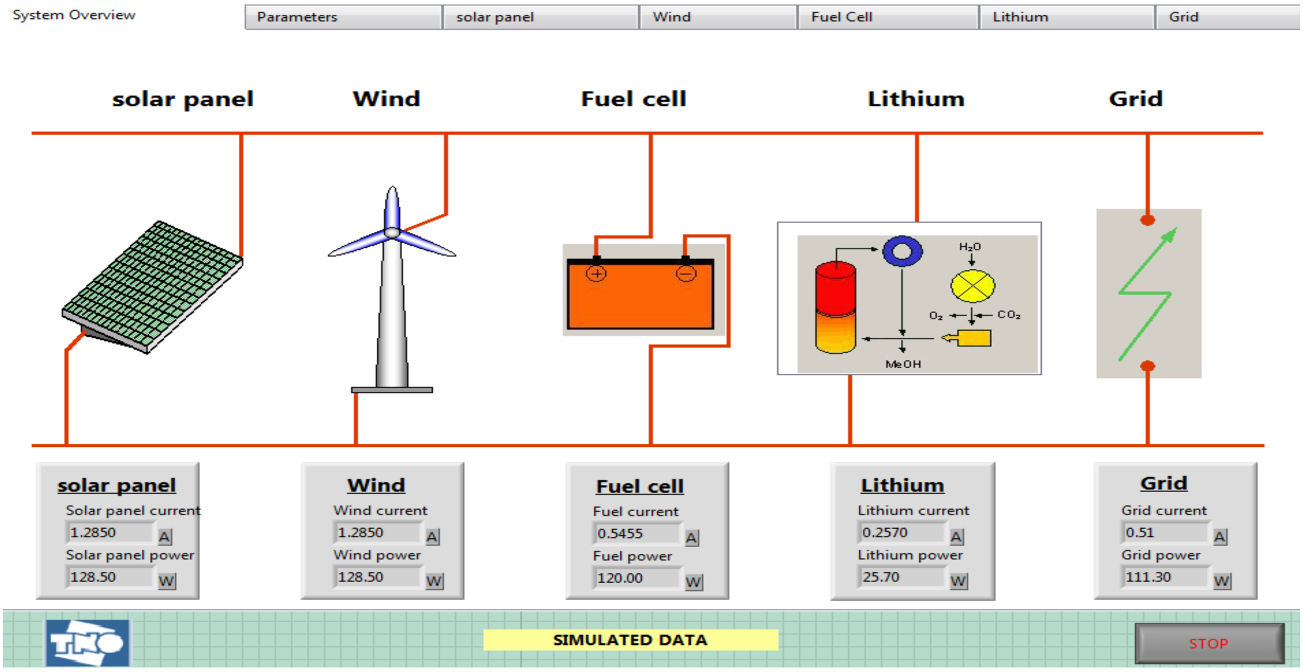

Figure 9: EMS showing the integrated testing of the proposed Dc microgrid system in Labview

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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