Battery Management using Fuzzy Logic Controller

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Abstract. This paper presents the design and implementation of battery energy management by using Fuzzy Logic Controller (FLC) for a renewable energy sources (Solar Panel, Wind Turbine). By using MATLAB/ Simulink, the modelling, analysis and control of the energy generator devices and energy storage devices (ESD) are proposed. FLC has been designed to control the battery charging/discharging mode to increase the life of battery.

1. Introduction

With reduced storage of energy sources like fuel and impact on environment, the use of renewable energy has become the goal for energy development. Now-a-days, solar, tidal, wind, biomass, geothermal are used as renewable energy sources. A general power system uses energy storage device to avoid power shortage and disturbance in distribution system. In energy management system (EMS) one energy source and one ESD is used to avoid power shortage. In the development of energy management system, a control method is required to optimize energy distribution.

![Diagram of power generator with EMS](image)

**FIGURE 1.** configuration of power generator with EMS

System configuration as shown in Fig.1 includes power generator, ESD and EMS. The power generator includes PV panel, wind turbines and fuel cell. The energy storage equipment includes Lithium-
ion, Nickel-Cadmium, Lead acid or Nickel-Metal-Hydride battery. In this approach Lithium-ion battery is used. Battery management system monitor the state of the battery by using various parameters, such as:

Voltage: total voltage, voltage of individual cells, minimum and maximum cell voltage.

Temperature: average temperature, coolant intake temperature, coolant output temperature or temperatures of individual cells.

State of Charge (SOC): it indicates the charge level of battery.

State of Health: a variously-defined measurement of the remaining capacity of the battery as % of the original capacity.

State of Power: the amount of power available for a defined time interval given the current power usage, temperature and other conditions.

Current: current in or out of the battery.

For battery management system soc of battery is considered to be most important parameter. different methods have been proposed to evaluate soc of battery, including fuzzy logic-based methods, Kalman filter based methods. in this paper FLC is used for battery management.

2. Power Generator Components

The modelling of EMS and ESD were built in MATLAB Simulink environment based on equivalent circuits of the components. The following section describes the model of each subsystem in detail:

**Power Generation using Photovoltaic panel**

![Equivalent circuit of Solar panel](image)

**FIGURE 2.** Equivalent circuit of Solar panel

Figure 2 shows the equivalent circuit of solar panel. Solar panel current equation is given in (1) to (3).

\[
I_{pv} = n_p I_{ph} - n_p I_r \left[ e^{\frac{q}{K T A n_s}} \frac{V_{pv}}{T_s} - 1 \right]
\]

Where,

- \(V_{pv}\) = output voltage of solar panel
- \(I_{pv}\) = output current of solar panel
- \(n_s\) = number of solar panels in series
- \(n_p\) = number of solar panels in parallel
- \(K\) = Boltzmann constant \((1.38*10^{-23}) J/k)\)
- \(q\) = electron charge \((1.6*10^{-19}) C)\)
- \(A\) = ideality factor \((1-2)\)
- \(T\) = surface temperature of solar panels
- \(I_r\) = reverse saturation current

The characteristics of reverse saturation current \(I_r\) varies with temperature as expresses in (2).

\[
I_r = I_{tr} \left( \frac{T_r}{T_c} \right)^3 e^{\left( \frac{q E_g}{K A T_c} \left( \frac{1}{T_r} - \frac{1}{T_c} \right) \right)}
\]

Where,

- \(T_c\) = reference temperature of solar panel
Irr = reverse saturation current of solar panel  
$E_g$ = energy band gap  

$$I_{ph} = \left[ I_{scr} + \alpha(T - T_r) \right] \frac{s}{100}$$

The required power from solar panel is 5KW. We simulate the solar panel in MATLAB Simulink to get the required power as the two solar arrays are connected in parallel with power rating of 180W each. In his solar arrays 14 panels are connected in series to get required output. The solar panel takes the input as constant solar irradiation and constant temperature of 1000 W/m² and 70 respectively.

### Power Generation using Wind Turbine

Wind Turbine technology has undergone a tremendous transformation in the last twenty years and now the wind power is playing an important role in the generation of electricity. The Wind Energy Conversion System converts wind energy to rotational energy and then to electrical energy. The output power of a wind turbine is determined by the wind velocity and size and shape of the wind turbine. By studying the modeling of the wind turbine, we can control the performance of the wind turbine to meet the desired operational characteristics. The maximum mechanical power generated by the wind turbine is expressed as

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

Where,

- $P_w$ = Power generated by the wind turbine W
- $\rho$ = density of the gas in the atmosphere (kg/m)
- $A$ = cross sectional area of the wind turbine blade (m²)
- $V$ = wind velocity (m/sec)
- $C_p$ = Wind turbine energy conversion coefficient.

According to Benf’s law, the maximum power that can be obtained is 59.3% of the total received wind power. A typical wind energy conversion system consists of wind turbine, generators, control system and the interconnection apparatus as shown in Fig.3.

**FIGURE 3.** Wind Energy Conversion System

The wind turbine power generation is depending upon wind speed. Output power of wind turbine varies with wind speed; hence wind turbine is not drawn the constant power. To maintain the constant output power, use pitch-control to change the rotor blades angle and thus the torque transferred to the generator and keep the speed/frequency ratio constant. We required output from wind energy is 1.5KW to fulfill the load demand.

### 3. Power Storage Device

**Battery**

In battery modelling, battery open circuit voltage $V_{oc}$ and internal resistance $R$ given as a function of battery SOC. To determine battery output, the most important parameter required is battery capacity. SOC is an alternative way to determine the battery capacity. The SOC of battery as shown in (4) gives the SOC in terms of charge/discharge current.
SOC(t) = SOC(t-1) + \int_0^t \frac{I}{C_{bat}}

Where,
SOC(t) = Battery state of charge at time
SOC(t-1) = Battery initial state of charge
I = charge/ discharge current
C_{bat} = battery capacity

Equation describing Battery power model:

\[
P_{ideal} = \frac{P_{actual} + P_{loss}}{V_{oc}}
\]
\[
P_{actual} = IV_{oc} - I^2R_{int}
\]
\[
P_{loss} = \frac{V_{oc}}{2R_{int}}\sqrt{4R_{int}P_{actual}}
\]
\[
I = \sqrt{\frac{V_{oc}^2 - 4R_{int}P_{actual}}{2R_{int}}}
\]
\[
V_{term} = V_{oc} - IR_{int}
\]

Where,
I = Current in Amps
V = Voltage in Volts
P = Power in Watts
R_{int} = Internal Resistance in Ω
e = Energy in Joules
SOC = State of Charge (%)

For better performance and longer life battery SOC should maintain between 0.7 to 0.95[2].

4. Energy Management Using Fuzzy Logic Controller

Energy management system controls the amount of energy flow among various components in order to satisfy the load demand. An effective management of energy exchanges between various components allows significant increase in efficiency and use of renewable energy sources causes reduction in pollution.

As shown in Fig.4, the system configuration of power generator with EMS which include three major blocks as solar panel, wind turbine, load and Lithium-ion battery. To design controller, the dynamic model of power sources is necessary. The photovoltaic system and wind turbine are nonlinear system and fuzzy logic controller offer a practical way for designing nonlinear control system.

The design of photovoltaic system and wind turbine required to maintain maximum power. The difference between actual power and generated power is taken to charge and discharge the Lithium-ion battery. The life and SOC of battery are depends on charge and discharge time of battery. To improve the life of battery, by using fuzzy controller we can maintain the SOC of battery at desired level.
Fuzzy logic controller

FLC was first proposed by Lotfi A. Zadeh of the university of California at Berkeley in 1965 paper. Advantages of FLC over PID controller is: it is simple to design; it provides a hint of human intelligence to the controller; it is cost effective; no mathematical modelling of system is required; linguistic variables are used instead of numerical one; non-linearity of the system can be easily handled; system response is fast; high degree of precision is achieved. There are basically three essential segments in FLC, these are 1) fuzzification block 2) inference system 3) defuzzification block. Instead of using numerical variables, fuzzy logic uses linguistic variables for processing information. But since the inputs to the FLC are in the form of numerical variables, they need to be converted into linguistic variable. This function of converting these crisp set into fuzzy set is performed by fuzzifier[3]. Membership function in fuzzy controller defines the degree of truth in fuzzy logic. Membership function characterize fuzziness, whether the elements in fuzzy sets are discrete or continuous.

Battery control using fuzzy controller

In this paper Lithium-ion battery was used as energy storage device. By comparing different types of batteries, the lithium-ion battery has longer life that is why here it is chosen. To obtain the desired SOC, the fuzzy controller is designed to be in charging or discharging mode. The input to the fuzzy logic controller is ΔSOC and ΔP as shown in (11) and (12) and output variable is current which is given input to the battery model.[4]

\[
\Delta \text{SOC} = \text{SOC}_{\text{command}} - \text{SOC}_{\text{new}}
\]
\[
P = P_{L} - (P_{\text{wind}} + P_{\text{pv}})
\]

The generated power is coming from solar panel power and wind turbine power. The total power is difference between load power and generated power by wind turbine and solar panel. The input and output membership function contain five grades: NB (negative big), NS (negative small), ZO (zero), PS (positive small), PB (positive big), as shown in fig. 5 and 6.

We can determine the membership function and substitute into scaling factor to obtain the current for charge and discharge. If the power is negative, the renewable energy system does not provide enough energy to the load then fuzzy controller forced to battery for discharge to fulfill the load demand. If the SOC of battery is greater than command SOC then ΔSOC is negative and battery must operate in discharge mode.
Table 1 shows the fuzzy control rules of proposed system. For example, when the input variable P is NB and ΔSOC is NB then the output variable I is PB. The command SOC given to fuzzy controller is 50% that is when the battery SOC becomes less than 50% then battery will charge and when the battery SOC becomes greater than 50% then battery will discharge. To extend the life of battery, fuzzy control rules are set to maintain battery SOC above 50%\[1\].

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

**TABLE 1.** Fuzzy rules of proposed system
5. Simulation Result

The battery management using fuzzy logic controller in MATLAB Simulink model is shown in Fig. 7. It consists of solar module of 5KW, wind turbine of 1.5 KW load of 6KW and Lithium-ion battery. The first input given to fuzzy controller is difference (ΔP) between the load power and power generated and initial SOC of battery and reference SOC difference (ΔSOC) given as second input to the controller. It gives the current as output which is fed back to the battery to charge and discharge. The proposed system with fuzzy logic controller can maintain the SOC of battery at certain level if initial value of SOC is low or high. Reference SOC given to the fuzzy controller is 40%, hence the SOC of battery is maintained at 40 %. The resultant of fuzzy rules on surface view is shown in Fig.8.

FIGURE 7. MATLAB Simulink model of Battery Management Using Fuzzy Logic Controller

FIGURE 8. Three-dimensional view of fuzzy rules

As shown in Fig.9, it is observed that the controller is able to maintain the battery SOC at 40% in both cases. Battery SOC is directly proportional to current. Hence as shown in waveform the SOC and current
waveforms are approximately similar in shape. As shown in Fig. 9 a) Command SOC is given 40% and battery initial SOC is 70%, hence battery discharges up to 40 and become stable. In this condition, battery current is constant 5A for some time and then it reduced. In Fig. 9 b) initial battery SOC is 30% which is less than Command SOC hence battery charging up to 40% and become stable.

![Simulation results showing initial a) SOC < 40% and b) SOC > 40%](image)

**FIGURE 9.** Simulation results showing initial a) SOC < 40% and b) SOC > 40%

### 6. Conclusion

This paper presents the modelling of solar panel and wind turbine with battery by using Fuzzy Logic Controller to achieve optimization of an energy management system. From the results, the battery SOC maintains the desired value to increase the life of battery by using fuzzy control rules and it also saves the surplus power generation from solar panel and wind turbine.

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