A FUZZY LOGIC CONTROLLER BASED BATTERY ENERGY MANAGEMENT SYSTEM FOR A MICROGRID

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ABSTRACT
This paper presents battery management system for a microgrid system using fuzzy logic controller. The microgrid system comprises of a wind turbine, PV array, battery storage, and a set of loads. The fuzzy logic controller is used to control the load scheduling activity during critical conditions with inadequate power storage in order to avoid a system black-out. Fuzzy logic controller helps in battery energy management system of nonlinear, time varying type process of charging and discharging. The fuzzy controller manages the desired state of charge to improve the life cycle of the battery and avoid overcharge and insufficient charge of battery. The proposed control system is implemented in MATLAB Simpower software. The comparisons with PI controller are also done in this paper. Results are presented and discussed.

KEYWORDS: *Energy management system (EMS), fuzzy logic control, state of charge, microgrid.*

I. INTRODUCTION

With expanded attention to the lessening of traditional energy sources and ecological harm brought about in expanded carbon dioxide emissions from coal-let go power era, the utilization of renewable energy have turned into the objective for power improvement. Current eco-friendly power energy sources utilized into power generation era incorporates: sun oriented, wind, geothermal, biomass, and tidal. A general power framework utilizes battery energy storage to keep away from a power blackout or power surges created by natural environmental factors. The late pattern of renewable energy advancement is a combination of distributed energy sources and power storage subsystems to form a little micro grid that can lessen loss of power from power transmission lines over long separations. Microgrid is defined as a group of distributed energy resources, distributed storage devices and distributed loads that operated in a controlled and coordinated way so as to improve the reliability of the local power supply and of the energy system.

The power connection between various micogrid constituents can be done through a direct current link or an alternating current link. Hybrid energy system has greater ability to provide higher quality and reliable power than a system on a single resource. Because of this hybrid energy system have caught worldwide research attention [1]-[4].A number of researches working in hybrid renewable energy system. A review of hybrid renewable energy system for electric power generation, control and application was presented in [1]. It presents some important things in the design and power management of hybrid renewable energy system. It present statistics on the present status and future trend of renewable energy generation, some difficult challenges facing the widespread arrangement of renewable energy generation technologies and perception for future research in this area are also presented. Technical and economical benefits of employing distributed generation was presented in [2].The major technical benefits are reduced line losses, reduced emission of pollutants, increased overall power efficiency, strengthen system reliability and safety etc. And major economical benefits are reduced health care costs due to better environment, reduced fuel cost due to increased overall efficiency etc. A multiagent fuzzy logic based energy management to control energy flow in the hybrid energy system was presented in [4]. A number of researches working for predicting the battery service life. An analytical model for predicting the remaining battery capacity of lithium-ion batteries was presented in [5].Application of voltage and current controlled voltage source inverters for distributed generation system was presented in [6]. The potential of using battery storage in the residential distribution grids to increase the penetration of photovoltaic's was reported in [7]. Renewable energy is changed over into dc and strike with energy storage components, and after that it is altered to ac and encouraged into the utility grid. This methodology can promptly adjust to existing electrical facilities and speed up utilization of renewable energy. To utilize renewable energy all the more effectively, dc power ought to be directly supplied to these loads. An arrangement of the dc-distributed framework with grid association is demonstrated in which a bidirectional inverter is introduced to regulate with dc-grid voltage inside of a certain reach [8].

Control and Operation of a dc microgrid with Variable Generation and Energy Storage was presented in [9]. Control of distributed generation system suggested in [10]–[11] utilize the system voltage level as a means of communication. Sources and storage elements are controlled to supply high reliability power to loads. Hierarchy of controllers for microgrid is reported in [12]. An Adaptive Control System for a dc microgrid for Data Centers was presented in [13]. Data centers call for electric power with high availability, and a possibility to reduce the electric losses. However, when the microgrid is operated in island mode, the sources must be able to perform voltage and frequency regulation. Different operation strategies of the sources have been studied in [14] and [15]. Using controllers with droop characteristics ensures load shedding, and voltage and frequency stability.

This paper is organized as follows .Section II of the paper introduces the system presentation. Section III shows modeling of system components. Section IV explains the battery management system and results of the study and discussions are reported. Section V gives the conclusion and future work.

II. SYSTEM PRESENTATION

The system configuration composed of solar power, wind power generation, lithium-ion Battery, dc load, ac/dc converter, controller as shown in Fig.1.

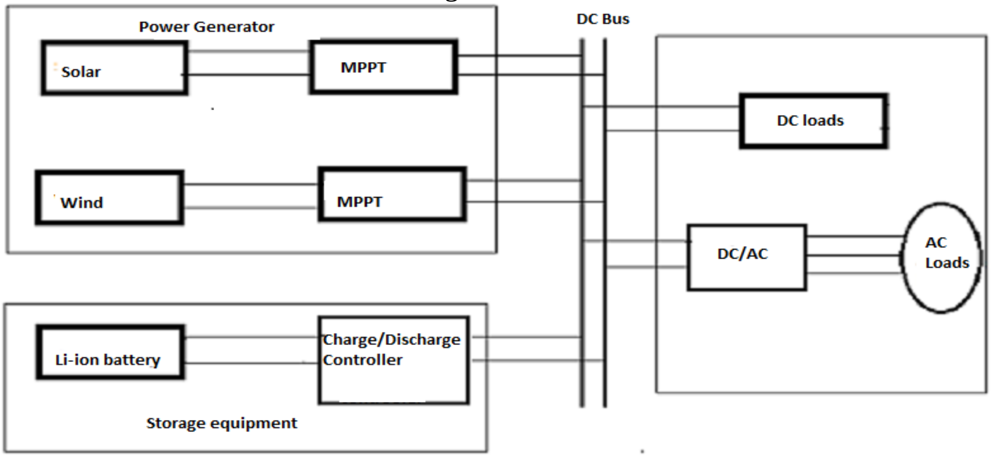

Figure.1. System Configuration of the proposed microgrid system

The whole system is called a hybrid energy system, because it consists of at least one inexhaustible source plus one extra source and one storage element to provide highly efficient system and greater balance in power supply. To control the energy flow among the elements associating a energy system, a suitable controller must be needed. As shown in Figure.1.the system consist of three major blocks: Power generator, storage equipment and load .The power generator consists of PV panels and wind turbine. PV panels and wind turbine are associated with maximum power point trackers to draw maximum power. In the system the output power is given to the loads with the greater priority. If the output power is excessive for the demands of the loads, the superfluous energy is utilise to charge the battery. Provided that the loads can't use up the complete output power, and the battery is completely charged, the extra power is then sent to the local distribution network if it present.

III. MODELING OF SYSTEM COMPONENTS

The system components can be modelled by making use of MATLAB simulink mathematical modules, based on equivalent circuits of the components.

3.1. Solar cell modelling

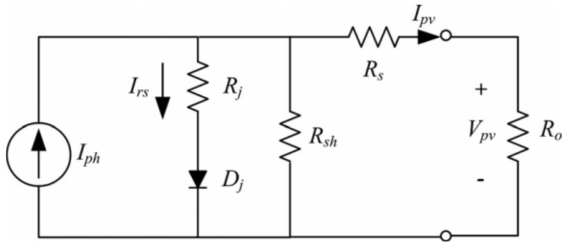

Figure. 2. Solar panel equivalent circuit.

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

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

where V_{pv} is solar panels output voltage, I_{pv} is solar panels output current, ns is number of solar panels in series, n_p 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^{-19}C), A is ideality factor (1–2), T is the surface temperature of the solar panels (k), and I_{rs} as reverse saturation current. The characteristic is reverse saturation current I_{rs} varies with temperature.

$$I_{rs} = I_{rr}\left[\frac{T}{T_r}\right]^3 exp\left(\frac{qE_9}{kA}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right) \quad (2)$$

WhereT_r is reference temperature of the solar panels (k), I_{rr} is the reverse saturation current of the solar panels at temperature T_r (K), and E_9 is energy band gap of the semiconductor material

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

where I_{scr} is the short-circuit current at reference temperature T_r and illumination intensity 1 kW/m2 , α is the short-circuit current temperature coefficient of the solar panels, and S is the illumination intensity (kW/m^2). The simulated output power verses output voltage of solar cell is shown in Figure. 3. This study used constant illumination intensity with varying V_{pV} for simulation verification.

3.2. Modelling of wind turbine

The power generated by wind turbine is expressed as

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

Where P_w is power generated by the wind turbine W, ρ 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), The density of gas ρ and energy conversion coefficient C_p in (4) is expressed by (5) and (6), respectively

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

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

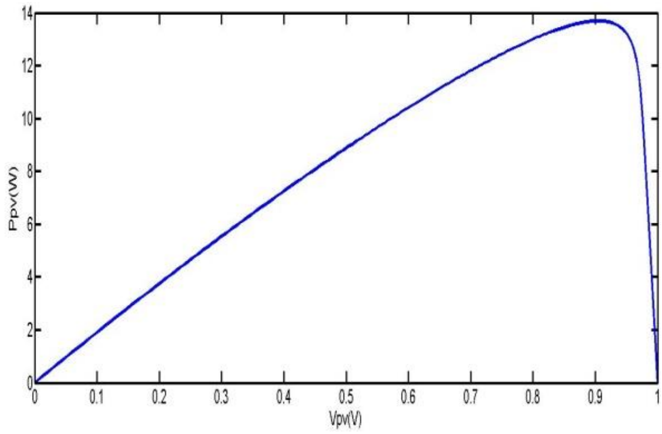

Figure.3. Simulated output power P_{pv} versus output voltage V_{pV} of the solar cell

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 λi in (6) and (8) is the expression of the initial tip speed ratio λ in (7)

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

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

The simulated output power Pw of the wind turbine with various wind speed V is shown in Figure.4.

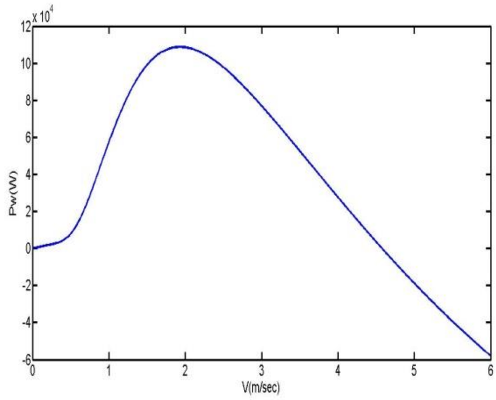

Figure.4. Simulated output power P_w versus various wind speed V

3.3. Lithium - Ion Battery Modelling

Among various batteries Lithium – ion battery have high energy density and efficiency, light weight and good life cycle. Eq. (9) is the discharge and Eq.(10) is the charge equation of Lithium-ion battery.

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

$$f_2(it\ i^*i) = E_0 - K.\frac{Q}{it+0.1.Q}.i^* - K.\frac{Q}{Q-it}.it + A.\exp(-B.it) \quad (10)$$

Where E_0 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 $(Ah)^{-1}$ .The battery state of charge is an sign of the power reserve. SOC of the battery is an important factor, which is calculated by

$$\mathrm{SOC} = 100\left(1 - \frac{\int_0^t idt}{Q}\right) \quad (11)$$

This study simulated with invariant discharge of 5 A for Validation and perception of SOC variety is indicated in Figure.5. From the simulated results, we can see the nonlinearity between SOC and voltage of lithium – ion battery. The SOC value of batteries has been elect as the design parameter inspite of battery voltage.

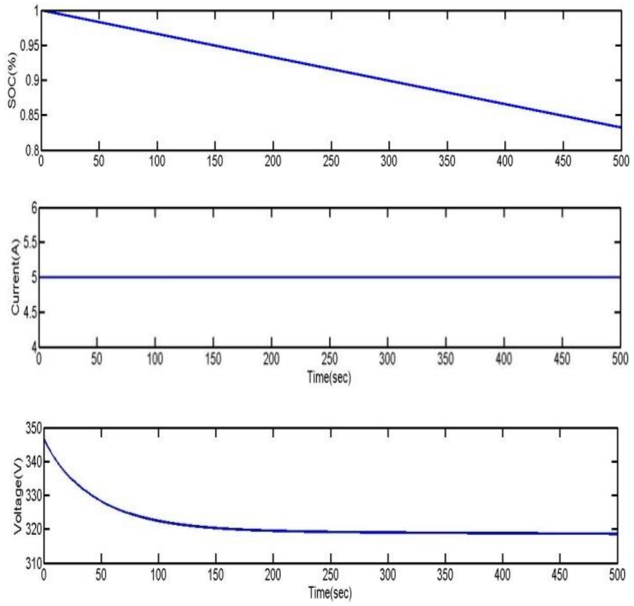

Figure.5. : Simulation results of battery with constant discharge of 5 A

IV. BATTERY MANAGEMENT SYSTEM

Fuzzy control is planned and actualized in energy management system to accomplish the enhancement of the system. The configuration model obliges that both the photovoltaic and the wind turbine are supplied by a maximum power point tracker to keep up the greatest working point. The difference between actual load and total generated power is considered for Li-ion battery in charge and discharge modes. The existence and SOC of the battery are in direct extent. To enhance the life of the Li-ion battery, we have to control and keep up the SOC of battery with fuzzy control. The control process of the battery charging and discharging is nonlinear and fuzzy logic offer a practical route for planning nonlinear control frameworks.

4.1. Fuzzy control

A fuzzy control is based on fuzzy-logic thinking in the design of how a controller operates. It yields a wider and more flexible space in logic deduction for the expression of conceptual ideas and experience. It employs a set of qualitative rules defined by semantic descriptions [11]-[13].
The fuzzy controller is applied in the proposed microgrid system as shown in Figure.6.

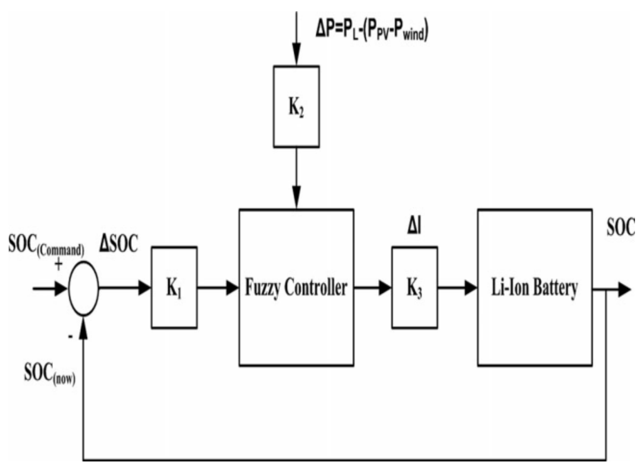

Figure. 6. Block diagram of fuzzy control to maintain the desired SOC of the battery.

To obtain the desired SOC value, the fuzzy logic controller is planned to be in charging mode or discharging mode for the proposed energy system. The input variables of the fuzzy control are ΔSOC and ΔP and output variable is ΔI. The input and output variables are defined as follows:

$$\Delta \mathrm{SOC} = SOCcommand - SOCnow \tag{12}$$

$$\Delta \mathrm{P} = P_L - (\mathrm{Pwind} + \mathrm{Ppv}) \tag{13}$$

The power difference ΔP is between required power for load and the total generated power of the proposed microgrid. The generated energy comes from solar power Ppv, wind power Pwind and load powerP_L. 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.7 and 8.

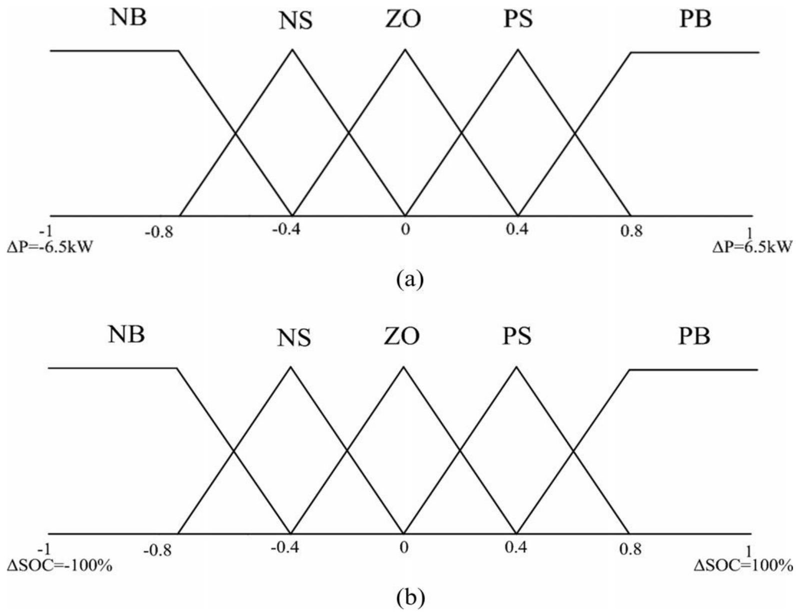

Figure. 7. Input membership functions of variables: (a) ΔP and (b) ΔSOC.

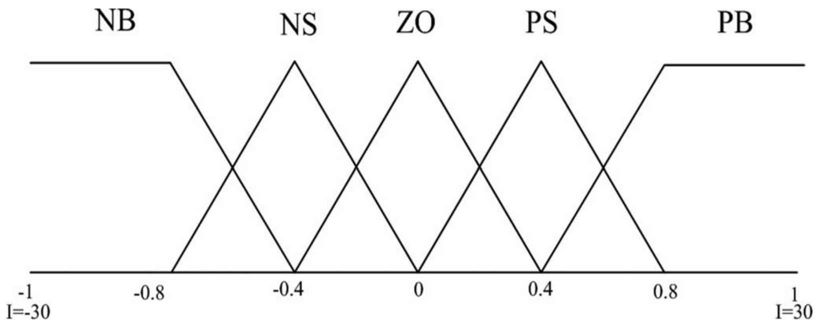

Figure. 8. Output membership function of variable ΔI.

Through scaling parameters K1 and K2, we can find out 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 power required for the load, the battery must be manipulated in charging mode; if the ΔSOC is negative, it means that the SOC of the battery is greater than the required SOC. Thus, the battery must operate in discharge mode.

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

The control rules of this study prioritize selling extra electricity generated by the renewable energy in response to the present control strategy of energy system development for selling electricity and increasing the life of Li-ion batteries. Table 1, shows the fuzzy rules of the proposed microgrid 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 inspite of NB when the system is manipulated in the above conditions because selling electricity is the first importance in this case. Hence, the fuzzy control table of the proposed microgrid system is not symmetrical. To increase the existence of storage batteries in the design of fuzzy control, the fuzzy control rules are set to maintain battery SOC above 50%. Furthermore, in the fuzzy control rules the Li-ion battery is forced to discharge as the control strategy when energy requirement at load was higher than the energy produced by the solar and wind energy**.**

4.2 Discussion and Result Analysis

The proposed microgrid system was implemented using MATLAB/SIMULINK software to control and monitor the energy system with two power sources: solar cell, wind turbine. The dynamic model of the proposed microgrid system by Fuzzy using MATLAB simulink is shown in Figure. 9, and by PI using MATLAB simulink is shown in Figure. 10.

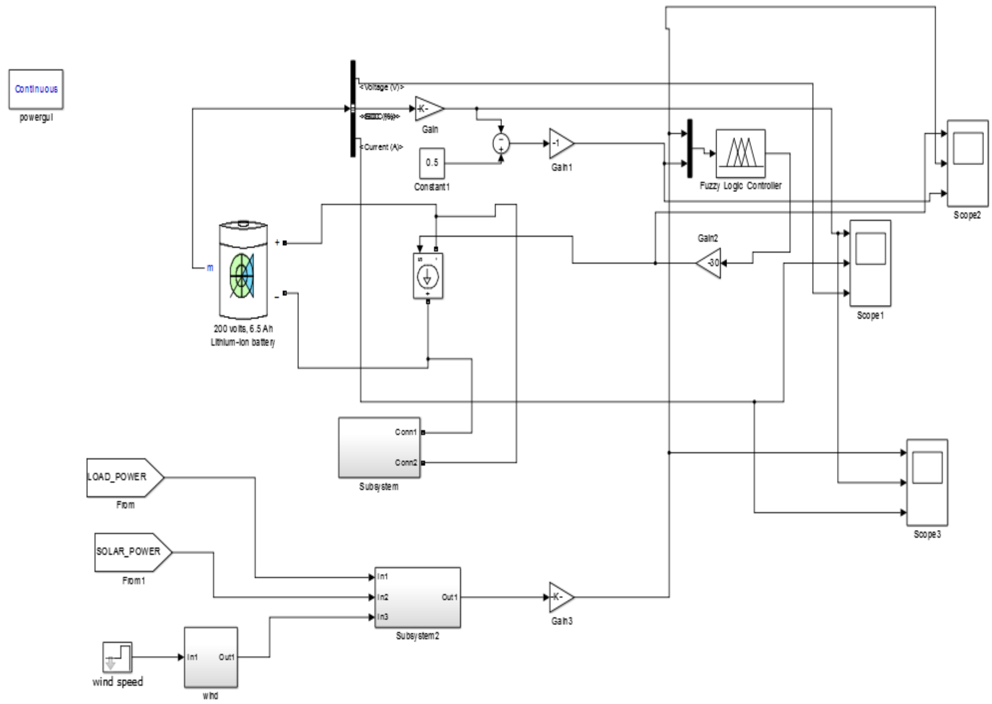

Figure.9. Dynamic model of the proposed microgrid system by Fuzzy using MATLAB simulink.

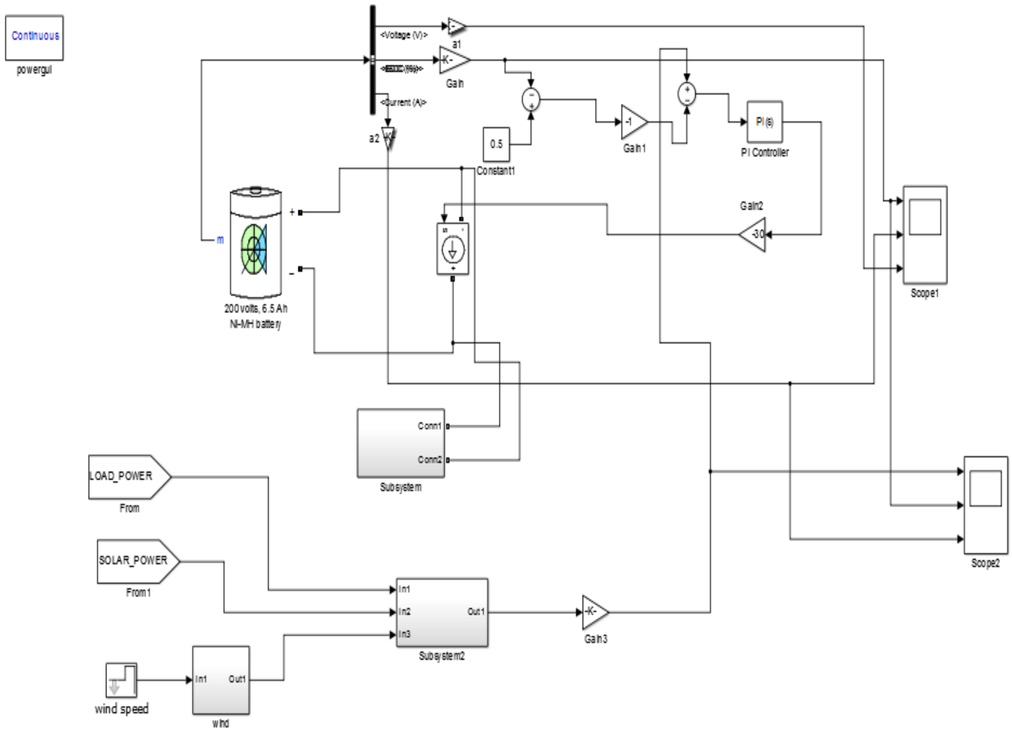

Figure.10.Dynamic model of the proposed microgrid system by PI using MATLAB simulink.

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 Figure. 11, the fuzzy and PI controller Li-ion battery SOC is maintained at 50% with an initial value of 10%, and Figure. 12 shows the fuzzy and PI controller Li-ion battery SOC maintained at 50% with an initial value of 90%.Figure.11 and Figure.12 shows comparison between Fuzzy and PI controller simulation result.

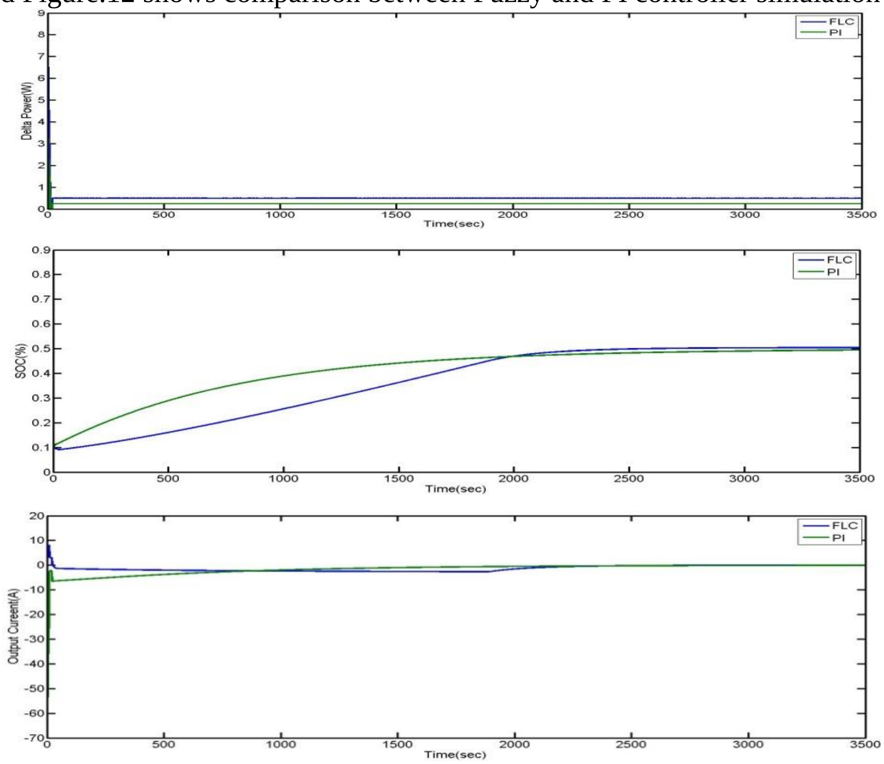

Figure.11. Simulation results with initial battery SOC at 10% using Fuzzy and PI Controller.

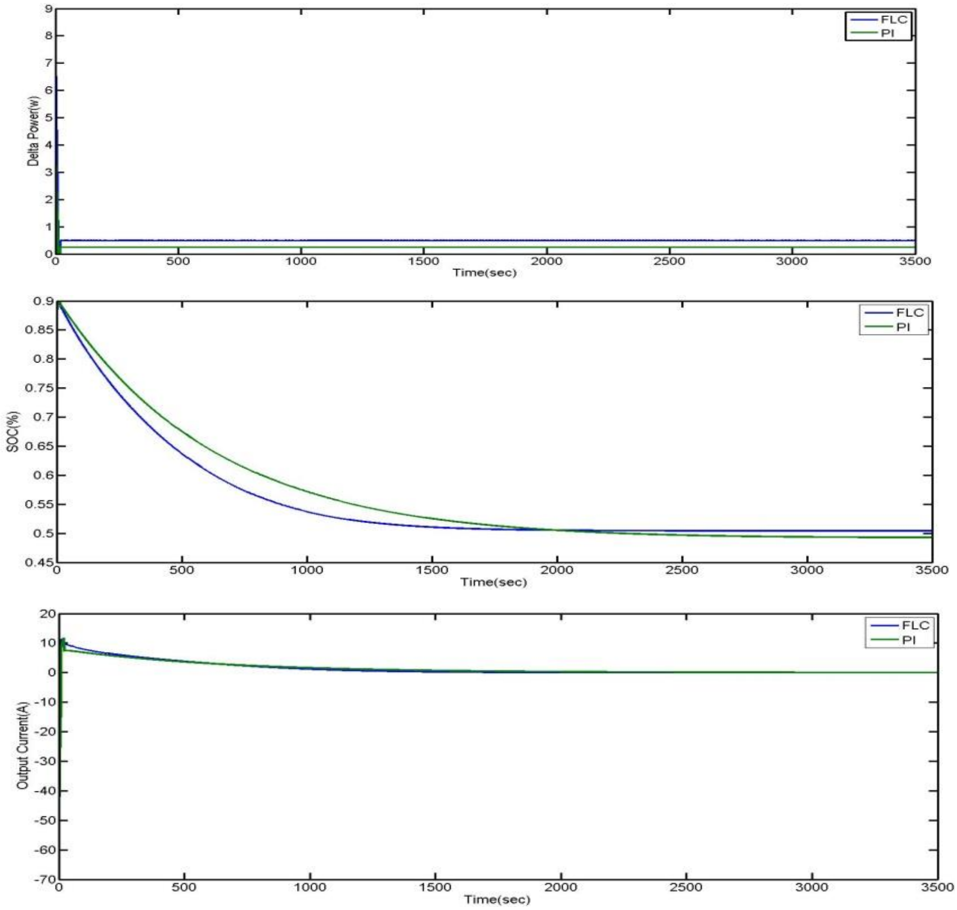

Figure.12. Simulation result with initial battery SOC at 90% using Fuzzy and PI controller

Where they obtained result shows that Fuzzy controller is better than PI controller, maximum overshoot and settling time values of fuzzy controller were much superior than that of PI controller. Rise time and settling time are also minimized. The control strategy of this study is to sell electricity as a priority and to maintain battery SOC.

V. CONCLUSION AND FUTURE WORK

This paper exhibits the modeling, analysis, and design of fuzzy control to accomplish optimization of the Battery management system for a microgrid system. The comparison of PI and Fuzzy control is done in this paper. In spite of the simple implementation of PI controller its response is not so good for non-linear system, where the obtained results shows that the response of load power in case of using the fuzzy control is better and faster than that obtained in case of using the PI controller. It also shows that the maximum overshoot and settling time values of the fuzzy logic controller were much better than those of the PI controller. There is considerable instability in settling time of responses by using PI controller. To overcome this instability Fuzzy controller has been used. Simulation results were obtained by developing dynamic microgrid system model. From the simulation results, the system achieves power equilibrium, and the battery SOC maintains the desired value for increase of battery life by using the control rules for a microgrid system. The charging and discharging control of battery is nonlinear, time varying process, so it is easy to obtain optimal operation performance using fuzzy control than that of PI control.
In future the optimization of energy management system for microgrid can be done using neuro and neuro-fuzzy control techniques for better performance.

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