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HYBRID AC-DC MICRO GRID WITH FUZZY LOGIC CONTROL OF PV SYSTEM, BATTERY AND CRITICAL LOAD

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Abstract: A power flow control method for a DC-AC Hybrid microgrid is proposed for pulsating loads. The hybrid micro grid consists of both AC & DC networks connected together by a multidirectional converter. In this microgrid network, it is especially difficult to support the critical load without incessant power supply. System efficiency has an important role in order to harvest the maximum available renewable energy from DC or AC sources whilst providing power backup capability. A control strategy is proposed in off grid islanded mode method based on the micro grid line frequency control as agent of communication for energy control between the DPG modules. A critical case is where the AC load demand could be lower than the available power from the photovoltaic solar array where the battery bank can be overcharged with unrecoverable damage consequences.The battery banks inject or absorb energy on the DC bus to regulate the DC side voltage. The frequency and voltage of the AC side are regulated by a bidirectional AC-DC inverter. The power flow control of these devices serves to increase the system's stability and robustness. The hybrid micro grid consists of both AC & DC networks connected together by a multidirectional converter. In this micro grid network, it is especially difficult to support the critical load without incessant power supply. In this paper, a fuzzy logic based hybrid micro grid with solar energy, energy storage and pulsating load is proposed.The system is simulated in MATLAB/SIMULINK.

Keywords: Fuzzy logic controller, Hybrid micro grid, Renewable energy sources, Photo voltaic system, Bidirectional converter.

I. INTRODUCTION

The ever increasing energy consumption, the soaring cost and the exhaustible nature of fossil fuel, and the worsening global environment have created increased interest in green [renewable based energy sources] power generation systems. Wind and solar power generation are two of the most promising renewable power generation technologies. The growth of wind and photovoltaic (PV) power generation systems has exceeded the most optimistic estimation. Nevertheless, because different alternative energy sources can complement each other to some extent, multisource hybrid alternative energy systems (with proper control) have great potential to provide higher quality and more reliable power to customers than a system based on a single resource [1]. Because of this feature, hybrid energy systems have caught worldwide research attention. Photovoltaic (PV) generation systems and isolated wind-electric systems are considered among therenewable

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systems to be viable alternatives for the designer of such remote power supplies. Nevertheless, systems based on either wind or solar energy is unreliable due to seasonal and diurnal variations of these resources. The control of such a scheme is also far from straightforward, especially where there is a high wind penetration [2]. Furthermore, it decreases the advantage of clean and no pollution energy achieved from the renewable sources. A system that is based fully on renewable resources but at the same time reliable is necessary and hybrid wind and solar systems with small battery storage meet these requirements [3].The main components of a micro grid are distributed generation sources such as photovoltaic panels, small wind turbines, fuel cells, diesel and gas micro-turbines etc and distributed energy storage devices such as batteries, super capacitors, flywheels etc and also critical and non-critical loads Energy storage devices are employed to compensate for the power shortage or surplus within the micro grid [4].Due to the nature of intermittence of renewable energy, the use of the secondary energy storage such as batteries become inevitable which will compensate the fluctuations of power generation. First, the renewable resource such as wind or tidal energy is used to drive a turbine, translating its power to mechanical form, which then drives a generator. The AC power generated is generally with a variable frequency and unstable voltage so it will be converted to DC power [5]. The DC power either is used to serve the load directly or converted to good quality AC power supply to AC loads. Due to uncertainties of the renewable energy availability, battery storage is adopted. So the electricity energy will be saved to the battery when the excessive electricity is generated and the stored energy will supply electricity to the load while there is no enough electricalMany Countries count on coal, oil andpower being generated. As we know, frequent charging and discharging will shorten the life time of a battery [6].With such a system, the problem is how to determine when the battery should be charged to provide the best energy efficiency and to prolong the life time. The proposed fuzzy control is to optimize energy distribution and to set up battery state of charge (SOC) parameters. A control strategy based on fuzzy control theory has been proposed to achieve the optimal results of the battery charging and discharging performance, and compared with a classical PI controller for performance validation [7-8].

II. PROPOSED SYSTEM MODELLING

A. PV panel Modelling

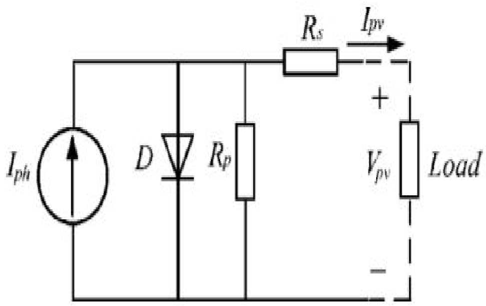

Fig.1. Equivalent circuit of a solar cell.

Fig.1 shows the equivalent circuit of a PV panel with a load. Following equations shows the mathematical model of a PV panel and its output current[7].

$$I_o = n_p I_{ph} - n_p I_{rs}[\exp(k_o v/n_s) - 1]$$

$$Ipv = npIph - npIsat * \left[\exp\left(\left(\frac{q}{Akt}\right)\left(\frac{Vpv}{ns} + IpvRs\right)\right) - 1\right] \quad (1)$$

$$Iph = (Isso + Ki(T - Yr)) * \frac{s}{1000}$$

$$Isat = Irr\left(\frac{T}{Tr}\right)\left(\frac{T}{Tr}\right)^3 \exp\left(\left(\frac{qEgap}{Ka}\right) * \left(\frac{1}{Tr} - \frac{1}{T}\right)\right) \quad (2)$$

B.Modelling of Lithium-ion battery bank

An accurate battery cell model is needed to regulate the DC bus voltage in islanding mode. The battery terminal voltage and SOC need to be estimated during operation. A high Fidelity electrical model of lithium-ion battery model with Thermal dependence is used [8]. The equivalent circuit of the Battery model is shown in Fig.3 The instantaneous response

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modelled by a resistor Ro and the hysteresis response is Modelled by a non-linear RC circuit R/ and C/. Emf represents the internal voltage of the battery. All four parameters are varying with different sacs and temperatures, so four lookup tables are established by using the parameter estimation Too box in Simulink Design Optimization for these four Parameters under different sacs and temperatures. The flow Diagram of the parameter estimation procedure is shown in

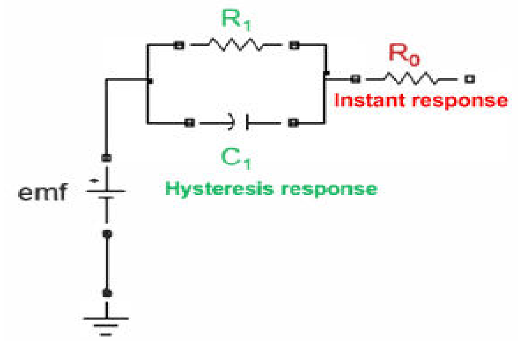

Fig.2 Lithium-ion battery equivalent circuit.

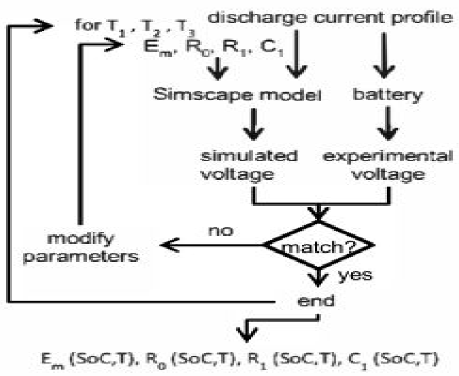

Fig.3. Flow diagram of the parameter estimation procedure.

Fig.3. The SOC of each single battery cell can be calculated by equation (3).

$$SOC = 100(1 + \frac{\int i_b dt}{Q}) \quad (3)$$

III.COORDINATED CONTROL OF THE CONVERTERS

Three types of converters are utilized in this proposed Hybrid micro grid. These converters must be actively controlled in order to supply uninterrupted power with high Efficiency and quality to critical loads on the AC and DC sides during islanding mode. The control method for the converters is discussed in this section.

A.Boost converter control with MPPT

In islanding mode, the boost converter of the PV farm operates in on-MPPT or off-MPPT which is based on the system's power balance and the SOCs of the battery banks. In most situations, this boost converter can operate in the on mode since the variation of the solar irradiance is much slower compared with the power adjustment ability of the AC generator. Therefore, for a given load either on the AC or DC side, the PV should supply as much power as possible to maximize its utilization. However, if the battery banks' SOCs are high (near fully charged) and the PV's maximum output

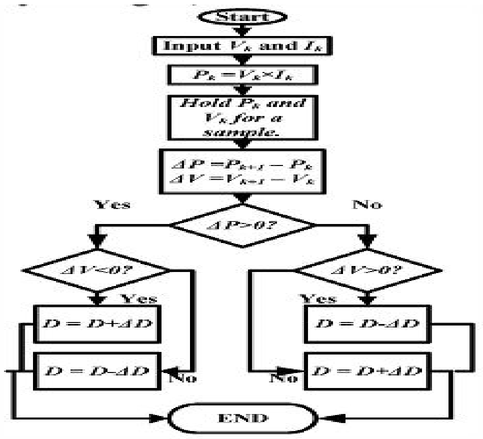

Fig.4. Flow chart of P&O MPPT Method.

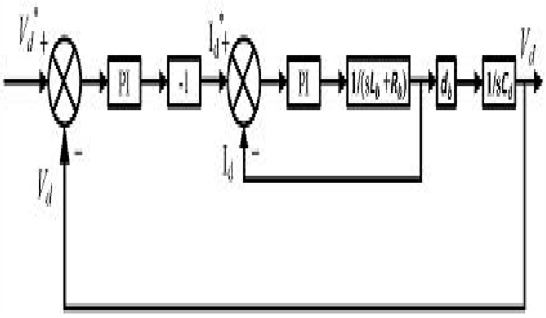

Fig.5.The control block diagram for bi-directional DC-DC converter.

power is larger than the total load in the hybrid micro grid, the PV should be turned to off-MPPT to help the system balance the power flow. In this paper, the

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perturbation and observe (P&O) method is used to track the maximum power point. The algorithm utilizes the PV farm output current and voltage to calculate the power. The values of the voltage and power at the k'h iteration (Pk) are stored, then the same values are measured and calculated for the (k+ J)'h iteration (Pk+,). The power difference between the two iterations (,dP) is calculated. The converter should increase the PV panel output voltage if tJP is positive and decrease the output voltage if tJP is negative, which [molly will adjust the duty cycle. The PV panel reaches the maximum power point when tJP is approximately zero. The flow chart of the P&Q MPPT algorithm is given is Fig.4.

B.Bi-directional DC-DC converter control

The bi-directional converters of the batteries play an important role in islanding mode to regulate the DC bus Voltage. A two closed-loops controller is used to regulate the DC bus voltage. The control scheme for the bi-directional DC DC converter is shown in Fig.5 The outer voltage controlled is used to generate a reference charging current for the Inner current controlled loop. The error between the measured DC bus voltage and the system reference DC bus voltage is set as the input of the PI controller, and the output is the reference Current. The inner current control loop will compare the Reference current signal with the measured current flow through the converter and finally generate a PWM signal to drive the IGBT STd or STc to regulate the current flow in the Converter. For example, when the DC bus voltage is higher Than the reference voltage, the outer voltage controller will Generate a negative current reference signal, and the inner current control loop will adjust the duty cycle to force the current flow from the DC bus to the battery, which results in Charging of the battery. The energy transfers from DC bus to the battery and the DC bus voltage will decrease to the normal Value. If the DC bus voltage is lower than the normal value, the Outer voltage control loop will generated a positive current Reference signal, which will regulate the current flow from the Battery to the DC bus and because of the extra energy injected from the batteries, the DC bus voltage will increase to the Normal value.

C.Bi-directional AC-DC inverter control

The frequency and voltage amplitude of the three phase AC side is not fixed during islanding operation so a device is Needed to regulate these variables. A bi-directional AC-DC

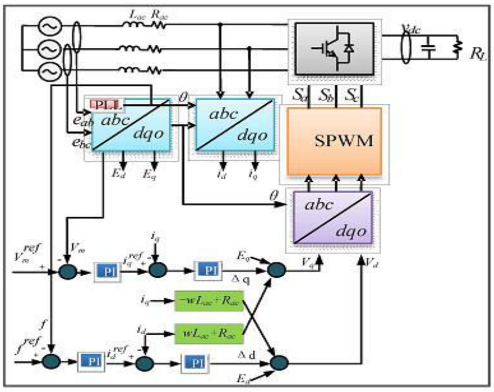

Fig.6. The control block diagram for bi-directional AC-DC converter.

inverter is used with the active and reactive power decoupling technique to keep the AC side stable. The Control scheme for the bi-directional AC-DC inverter is shown in Fig.6. in d-q cord mates, Id IS controlled to regulate the active power flow Through the inverter to regulate the AC side frequency, and Iq is Controlled to regulate the reactive power flow through the Inverter to regulate the AC side voltage amplitude. Multi-loop control is applied for both frequency and Voltage regulation. For frequency control, the error between measured frequency and reference frequency is sent to a PI Controller which generates the id reference. To control the

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Voltage amplitude, the error between the measured voltages amplitude and the reference voltage amplitude is sent to a PI Controller to generate iq reference. Equations (4) and (5) show The AC side voltage equations of the bi-directional AC-DC Inverter in ABC and d-q coordinate respectively. Where (Va, Vb, Vc) are AC side voltages of the inverter, and (Ea, Eb, Ee) are the voltages of the AC bus. (Lla, LIb, LIe) are the adjusting signals After the PI controller in the current control loop.

$$L_{ac}\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + R_{ac}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} - \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} + \begin{bmatrix} \Delta_a \\ \Delta_b \\ \Delta_c \end{bmatrix} \quad (4)$$

$$L_{ac}\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -R_{ac} & \omega L_{ac} \\ -\omega L_{ac} & -R_{ac} \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} V_d \\ V_q \end{bmatrix} - \begin{bmatrix} E_d \\ E_q \end{bmatrix} + \begin{bmatrix} \Delta_d \\ \Delta_q \end{bmatrix} \quad (5)$$

When the pulse load is connected or disconnected to the AC side, the frequency or the voltage amplitude will be altered. After detecting the variance from the phase lock loop (PLL) or voltage transducer, Id and Iq reference signals will be adjusted to regulate power flow through the bi-directional AC-DC Inverter. Because of the power flow variances, the DC bus Voltage will also be influenced. The DC bus voltage transistor will sense the voltage variance in the DC bus, and the bidirectional DC-DC converter will regulate the current flow Between the battery and the DC bus. In the end, the energy is transferred between the battery and the AC side to balance the Power flow in the system.

IV.FUZZY LOGIC CONTROLLER

Fuzzy logic theory is considered as a mathematical approach combining multi-valued logic, probability theory, and artificial intelligence to replicate the human approach in reaching the solution of a specific problem by using approximate reasoning to relate different data sets and to make decisions. The performance of Fuzzy Logic Controllers is well documented in the field of control theory since it provides robustness to dynamic system parameter variations as well as improved transient and steady state performances. In this study, a fuzzy logic based feedback controller is employed for controlling the voltage injection of the proposed Dynamic Voltage Restorer (DVR).Fuzzy logic controller is preferred over the conventional PI and PID controller because of its robustness to system parameter variations during operation and its simplicity of implementation. Since the proposed DVR uses energy storage system consisting of capacitors charged directly from the supply lines through rectifier and the output of the inverter depends upon the energy stored in the dc link capacitors. But as the amount of energy stored varies with the voltage sag/swell events, the conventional PI and PID controllers are susceptible to these parameter variations of the energy storage system; hence the control of voltage injection becomes difficult. The proposed FLC scheme exploits the simplicity of the Mamdani type fuzzy systems that are used in the design of the controller and adaptation mechanism.

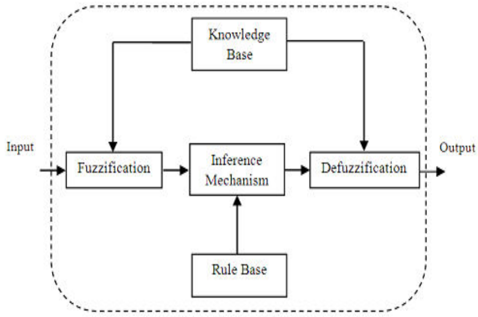

Fig.7 Schematic representation of Fuzzy Logic Controller.

The fuzzy logic based control scheme (Fig.7) can be dividedinto four main functional blocks namely Knowledge base,Fuzzification, Inference mechanism and Defuzzification. Theknowledge base is composed of data base and rule base. Database consists of input and output membership functions andprovides information for appropriate fuzzification anddefuzzification operations. The rule-base

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consists of a set oflinguistic rules relating the fuzzified input variables to thedesired control actions. Fuzzification converts a crisp inputsignals, error (e), and change in error (ce) into fuzzified signalsthat can be identified by level of memberships in the fuzzy sets.The inference mechanism uses the collection of linguistic rulesto convert the input conditions to fuzzified output. Finally, thedefuzzification converts the fuzzified outputs to crisp controlsignals using the output membership function, which in thesystem acts as the changes in the control input (u).The typical input membership functions for error and change inerror are shown in Fig 8a and Fig 8b respectively, whereas theoutput membership function for change in control input isshown in Fig 8c. The output generated by fuzzy logic controllermust be crisp which is used to control the PWM generation unitand thus accomplished by the defuzzification block. Manydefuzzification strategies are available, such as, the weightedaverage criterion, the mean-max membership, and center-of-area(centroid) method. The defuzzification technique used here isbased upon centroid method.

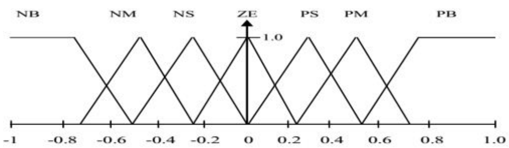

Fig 8a: Membership Function for Input Variable Error, 'e'.

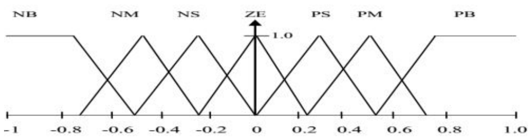

Fig 8b: Membership Function for Input Variable Change inError, 'ce'.

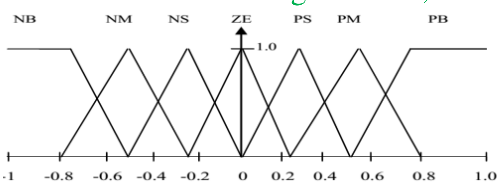

Fig 8c: Membership Function for Output Variable Changein Control Signal, 'u'.

The set of fuzzy control linguistic rules is given in Table 1. Theinference mechanism of fuzzy logic controller utilizes theserules to generate the required output.

Table 1. Rule Base for Fuzzy Logic Controller

'e' / 'ce'	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

V.MATLAB/SIMULINK RESLUTS

Case I: The proposed micro grid with pulse load variation without DC support.

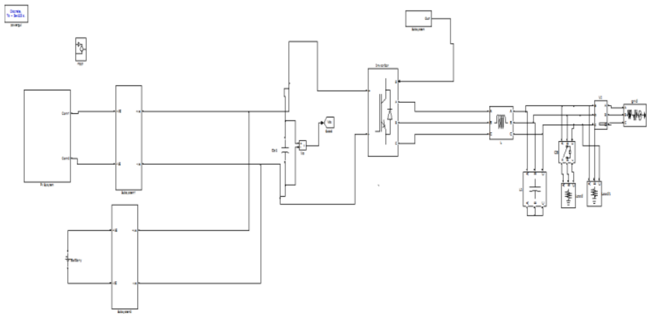

Fig.9. Matlab Simulink model of the proposed micro grid.

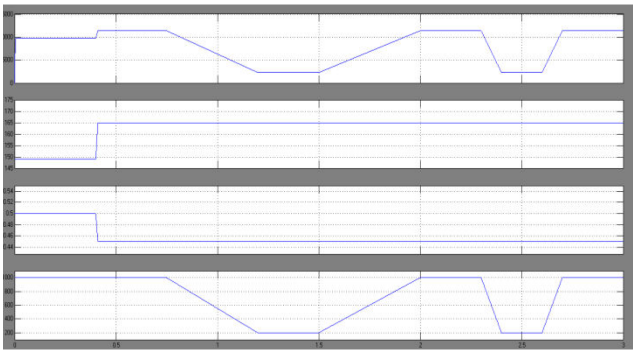

Fig.10. PV farm output power control with MPPT.

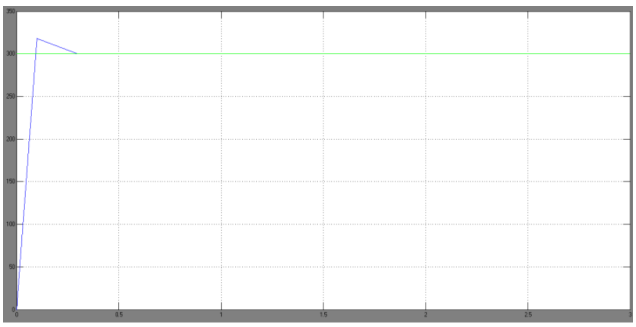

Fig.11. DC bus voltage with the influence of solar irradiance variation andpulse load

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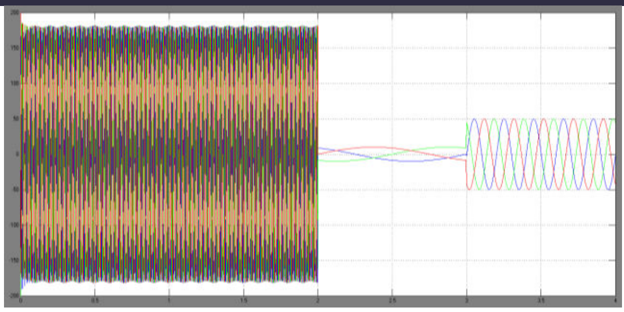

Fig.12. Ac Bus voltage with Pulse load influence.

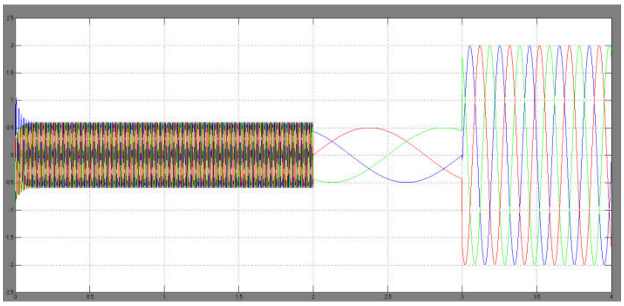

Fig.13. Ac Bus Current with Pulse load influence.

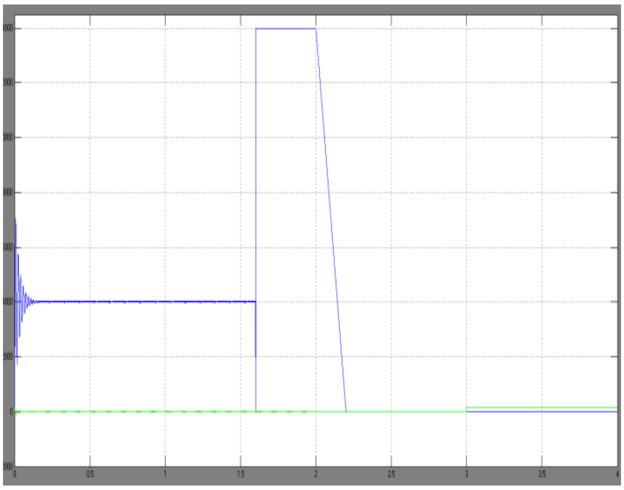

Fig.14. Generator active and Re-active power.

Case II: The proposed micro grid with pulse load variation with DC support.

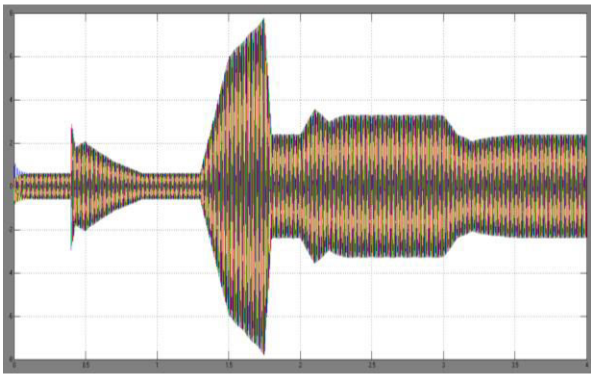

Fig.15. Ac side current with Ac pulse load influence.

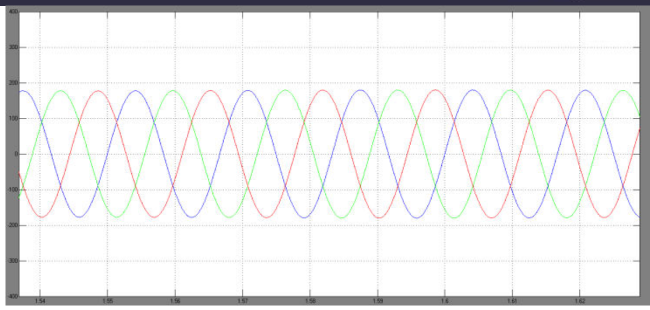

Fig.16. Microgrid AC side voltage and current response with DC support.

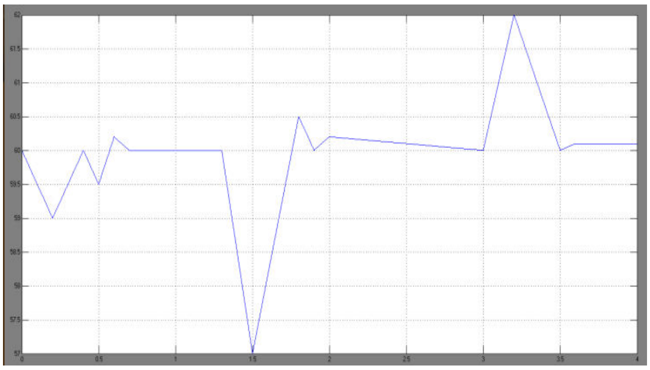

Fig.17. Ac Side frequency response.

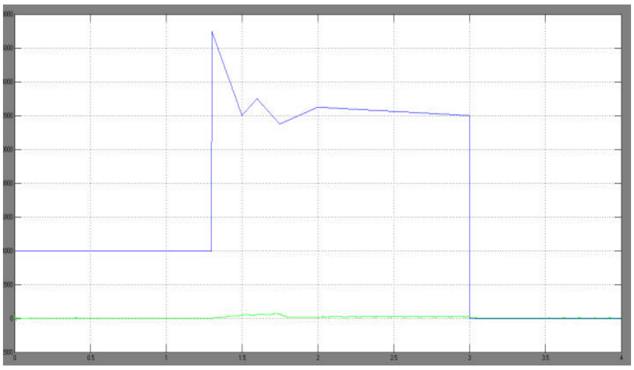

Fig.18. Generator side output active and reactive power.

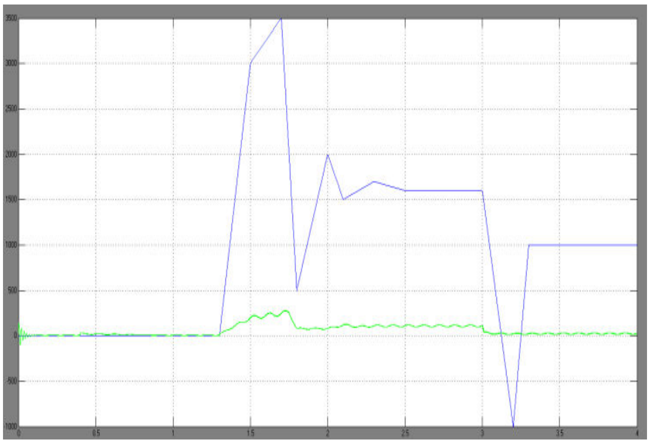

Fig.19. Ac side active and reactive power with pulse load.

Case III: The proposed micro grid with fuzzy controller with pulse load variation with DC support.

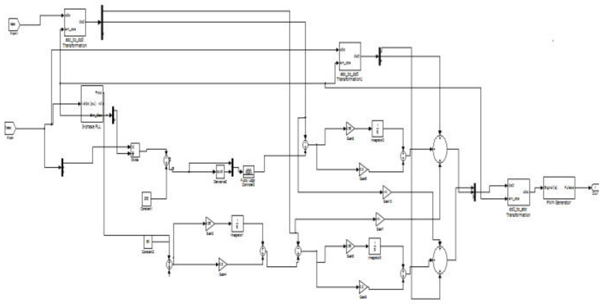

Fig.20. Fuzzy controller for proposed Micro grid.

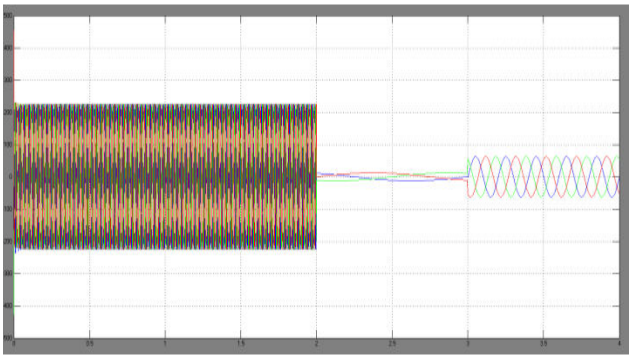

Fig.21. Ac Bus voltage with Pulse load influence with Fuzzy Controller.

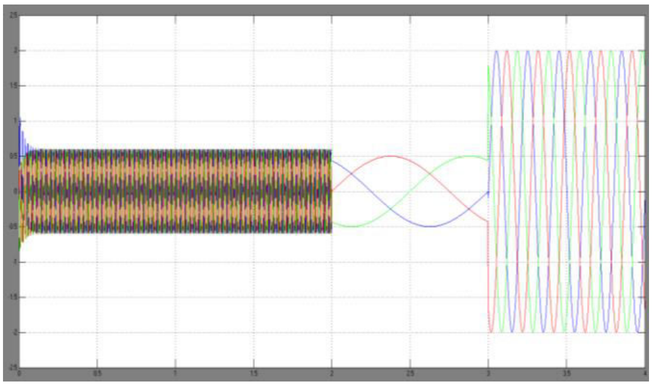

Fig.22. Ac Bus Current with Pulse load influence with Fuzzy controller.

VI.CONCLUSION

This paper presents the modelling, analysis, and design of fuzzy control to achieve optimization of a Battery management system for a solar hybrid system. According to the variation of the wind speed, solar isolation and the load demand, the fuzzy logic controller used to works effectively by turning on and off the batteries. Simulation results were obtained by developing a detailed dynamic hybrid system model. From the simulation results, the system achieves power equilibrium, and the battery SOC maintains the desired value for extension of battery life.Battery banks are connected to the DC bus throughbi-directional DC-DC converter. The AC side voltageamplitude and frequency are regulated by the bi-directionalAC-DC inverter. The system topologies together with the control algorithm are tested with the influence of pulse load. Thesimulation results show that the proposed fuzzy logic control based microgrid with thecontrol algorithm can greatly enhance the overall systemefficiency,stability, and robustness.

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