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Smart Controller for Standalone Hybrid Energy System in Mobile Telephony Industry

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Abstract

The main objective of hybrid energy system is to satisfy the demand of the electrical loads and at the same time maximise utilization of renewable energy sources while optimizing the operation of the battery bank and conventional power source that is Diesel Generator(DG) or Grid Power. In this paper the control and energy management strategy of a hybrid energy system, employing diesel and locally available wind and solar energies, is proposed. To develop the control strategy of hybrid system, the fuzzy controller is used to control overall system at supervisory level, which determines the reference currents for DC-DC converters and state of charge (SOC) of battery bank for energy management. The fuzzy controller is used to manage the energy supply as per Base Transceiver station (BTS) load demand throughout the year continuously. To obtain maximum energy output from the Wind Turbine (WT) and Photo Voltaic (PV) arrays. As wind speed and solar insolation vary, fuzzy based hybrid controller is used to control and operate the hybrid system under different modes of operation. These modes of operation depend upon the availability of wind and solar energy.

***Keywords*— Wind-Solar Energy, Fuzzzy Controller, Hybrid Energy System, Base Transceiver Station, Mobile Telephony**

I. INTRODUCTION

Obtaining reliable and cost effective power solutions for the worldwide expansion of telecommunications into rural and remote areas presents a very challenging problem. Grids are either not available or their extensions can be extremely costly in remote area. Although initial costs are low, powering these sites with generators require significant maintenance, high fuel consumption and delivery costs due to hike in fuel prices. A sustainable alternative to power remote base station sites [13] is to use renewable energy sources. All over the world different telecom companies [14], [15] are working in the direction of renewable energy application for base station sites.

The availability of renewable energy resources [1] at mobile base station sites is an important factor to develop the hybrid system. Many parts of the India wind and solar energy are abundantly available. These energy sources are intermittent and naturally available; due to these factors our first choice to power the mobile base station will be renewable energy sources such as wind and solar [8].

The task for the hybrid energy system controller [4] is to control the interaction of various system components and control power flow within the system to provide a stable reliable and economical source of energy. One of the main problems of the Hybrid Energy Systems [HES] is related to the control and supervision [3], [7] of the power distribution system.

A hybrid energy system combining variable speed WT and PV array generating system is presented to supply continuous power to the stand-alone BTS load. The WT and PV [4] are used as main energy sources, while the battery and diesel generator is used as back-up energy source. The main objective of the fuzzy controller [6] is to satisfy the load power demand and to maintain the SOC of the battery bank

The hybrid controller determines the operation mode of each generation subsystem using sliding mode control technique [2]. Fundamentally, these operation modes are determined by the energy balance between the total demand (load and battery bank) and the total generation (wind, solar and conventional diesel generator or Grid).

To design the fuzzy based [12] supervisory controller, we select the wind subsystem [9] and solar subsystem [5] as the main energy generation source and in the complementary roles are kept the DG and battery respectively. The complete diagram of Hybrid Energy System (HES) including the interaction with the Fuzzy Hybrid Controller is presented in Fig. 1.

The supervisor inputs are measure variables as the currents and voltages outputs of the subsystems in the hybrid energy system (HES) and the SOC (state of charge) of the battery bank. The supervisor controller outputs are the signals to activate or deactivate each subsystem.

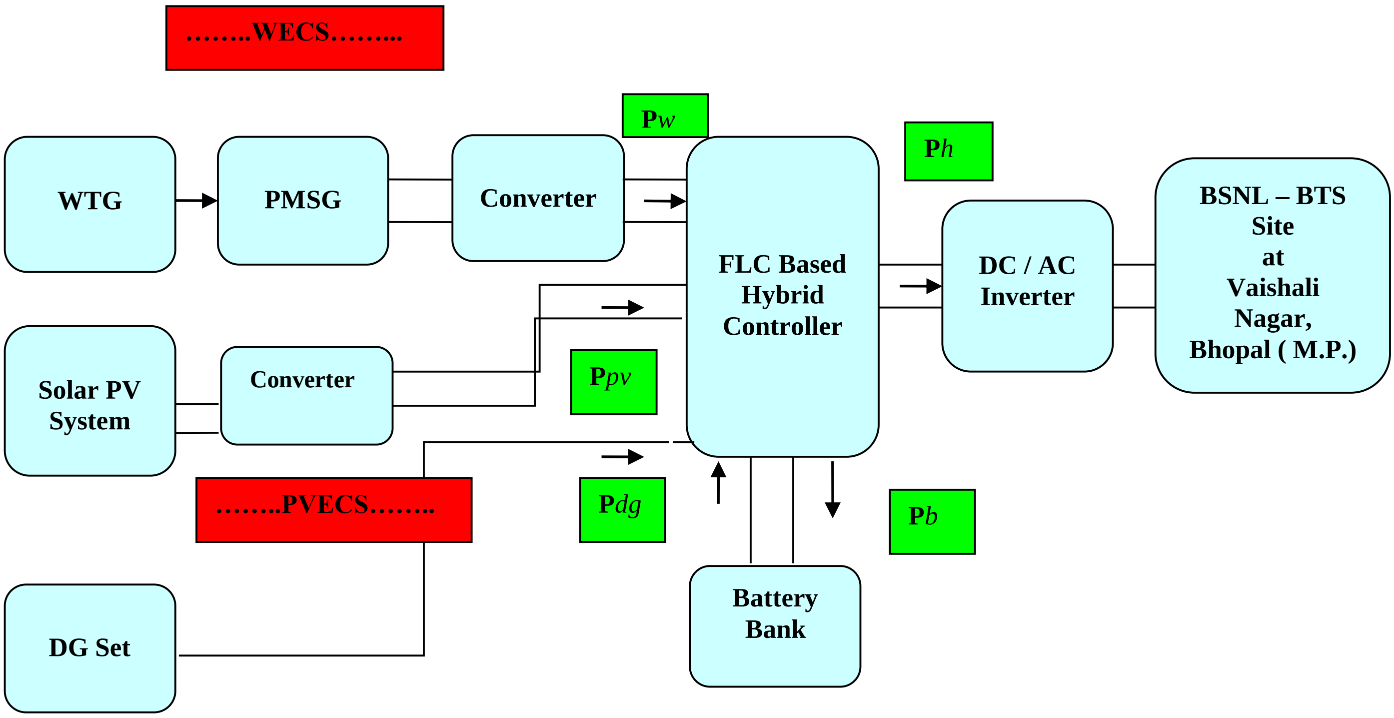

Fig. 1 Hybrid energy controller interaction model

2. Hybrid Controller Modes of Operation

To achieve the objective, we select five modes of operation as follow. The main idea of the first three modes was proposed in [2], the latest three modes were added to accomplish the control technique of Hybrid energy system for BTS load. Mode 3 was modified to match the battery bank control strategy with the supervisor control. Mode 4 and mode 5 are proposed for Diesel generators. Mode six are proposed for battery as well as diesel generator both are running and fulfil the load demand. All six modes of operation of supervisory control strategy are accomplished by fuzzy based hybrid controller.

A. *Mode-I operation*

Mode one occurs when the wind generation is sufficient to satisfy the total demand. The solar subsystem and the diesel generator are inactive even as the battery bank is in recharge mode at maximum charging current if it is discharged or at zero current if it is fully charged, and the wind subsystem is set to power regulation. This mode is running until the maximum available wind power is exceed by the total power demand.

$$\text{If}\ \{\omega_r \geq \omega_{mSW}\ \begin{cases} \text{Wind Subsystem} \rightarrow \begin{cases} \text{Power Regulation} \\ P_{w\,ref1} = V_b(i_L + i_{bref}) \end{cases} \\ \text{Solar Subsystem} \rightarrow \text{Inactive} \\ \text{Battery Bank} \rightarrow \begin{cases} \text{Recharge Cycle} \\ I_{bref} + \end{cases} \\ \text{Diesel Generator} \rightarrow \text{Inactive} \\ \text{BTS Load} \rightarrow \text{Inactive} \end{cases}$$

B. *Mode-II operation*

On this mode, the wind generation is not enough to satisfy the total demand and it is set by the fuzzy based hybrid controller to operate at the point of maximum energy conversion. The solar subsystem is set to follow a power reference required to complement the wind subsystem and together satisfy the total power demand of BTS site. The battery bank is part of the total power demand, because it is in recharge cycle, and its current is always the battery reference current.

$$\text{If} \begin{cases} \omega_m < \omega_{mSW} \\ -\dfrac{\partial I_{pv}}{\partial V_{pv}} V_{pv}^2 \geq P_{ref} \end{cases} \begin{cases} \text{Wind Subsystem} \rightarrow \begin{cases} \text{Maximum Power Conversion} \\ P_{w\,ref2} = K_{opt}\omega_m^3 - \dfrac{3}{2}(i_q^2 + i_d^2)r_s \end{cases} \\ \text{Solar Subsystem} \rightarrow \begin{cases} \text{Power Regulation} \\ P_{S\,ref} = v_b(i_l + I_{bref} - i_w) \end{cases} \\ \text{Battery Bank} \rightarrow \begin{cases} \text{Rechargable Cycle} \\ I_{bref} + \end{cases} \\ \text{Diesel Generator} \rightarrow \text{Inactive} \\ \text{BTS Load} \rightarrow \text{Inactive} \end{cases}$$

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C. *Mode-III operation*

On this mode, the wind and the solar subsystems are set to operate at their maximum energy conversion points, and the battery bank is set to supply power to the BTS load instead to receive energy.

This mode is maintained as long as the state of charge of the battery bank is greater than a minimum required or the battery current is higher than the maximum discharging current.

$$\text{If}\begin{cases}\omega_m < \omega_{mSW}\\ -\dfrac{\partial I_{pv}}{\partial V_{pv}}V_{pv}^2 < P_{ref}\\ |I_b| \le I_{bref} -\\ i_L > i_{gen}\end{cases}\begin{cases}\text{Wind Subsystem} \rightarrow \begin{cases}\text{Maximum Power Conversion}\\ P_{w\,ref2} = K_{opt}\omega_m^2 - \dfrac{3}{2}(i_q^2 + i_d^2)r_s\end{cases}\\ \text{Solar Subsystem} \rightarrow \begin{cases}\text{MPOP Tracking}\\ \dfrac{\partial I_{pv}}{\partial V_{pv}} + \dfrac{I_{pv}}{V_{pv}} = 0\end{cases}\\ \text{Battery Bank} \rightarrow \text{Able to Supply Power to the Load}\\ \text{Diesel Generator} \rightarrow \text{Inactive}\\ \text{BTS Load} \rightarrow \text{Inactive}\end{cases}$$

D. *Mode-IV operation*

In this case, the BTS site load demands is higher than the power available from renewable sources, and the battery bank current is equal or higher than maximum discharging current.

The hybrid controller automatically turns on to the Diesel generator to provide the extra current. On this mode, the battery current is always the maximum discharging current.

$$\text{If}\begin{cases}\omega_m < \omega_{mSW}\\ -\dfrac{\partial I_{pv}}{\partial V_{pv}}V_{pv}^2 < P_{ref}\\ \\ i_L > i_{gen}\end{cases}\begin{cases}\text{Wind Subsystem} \rightarrow \begin{cases}\text{Maximum Power Conversion}\\ P_{w\,ref2} = K_{opt}\omega_m^3 - \dfrac{3}{2}(i_q^2 + i_d^2)r_s\end{cases}\\ \text{Solar Subsystem} \rightarrow \begin{cases}\text{MPOP Tracking}\\ \dfrac{\partial I_{pv}}{\partial V_{pv}} + \dfrac{I_{pv}}{V_{pv}} = 0\end{cases}\\ \text{Battery Bank} \rightarrow \begin{cases}\text{Supplying Power to the load}\\ I_{bref} -\end{cases}\\ \text{Diesel Generator} \rightarrow \text{Able to supply power to the load}\\ \text{BTS Load} \rightarrow \text{Active}\end{cases}$$

E. *Mode-V operation*

On this mode, the total demand is more than the power available from wind and solar subsystems, and the battery bank is discharged.

The Hybrid controller allows the Diesel generator to starts taking the load gradually from the battery to supply the power demand. On this mode, the battery current is always zero.

$$\text{If}\begin{cases}\omega_m < \omega_{mSW}\\ -\dfrac{\partial I_{pv}}{\partial V_{pv}}V_{pv}^2 < P_{ref}\\ SOC \le Q_{min}\\ i_L > i_{gen}\end{cases}\begin{cases}\text{Wind Subsystems} \rightarrow \begin{cases}\text{Maximum Power Consumption}\\ P_{w\,ref2} = K_{opt}\omega_m^3 - \dfrac{3}{2}(i_q^2 + i_d^2)r_s\end{cases}\\ \text{Solar Subsystem} \rightarrow \begin{cases}\text{MPOP tracking}\\ \dfrac{\partial I_{pv}}{\partial V_{pv}} + \dfrac{I_{pv}}{V_{pv}} = 0\end{cases}\\ \text{Battery Bank} \rightarrow \begin{cases}\text{Completely Discharged}\\ I_b = 0\end{cases}\\ \text{Diesel Generator} \rightarrow \text{Active}\\ \text{BTS Load} \rightarrow \text{Acitve}\end{cases}$$

F. *Mode-VI operation*

On this mode, The Hybrid controller allows the Diesel generator and battery simultaneously start to fulfill the load demand.

On this mode, the battery current is increasing and DG current are set to constant current. This mode will be used rarely.

$$\text{If}\begin{cases}\omega_m < \omega_{mSW}\\ -Ppv < P_{ref}\\ ib > ibref -\\ i_L > i_{gen}\end{cases}\begin{cases}\text{Wind Subsystem} \rightarrow \text{inactive}\\ \text{Solar Subsystem} \rightarrow \text{inactive}\\ \text{Battery Bank} \rightarrow \begin{cases}\text{Supplying Power to the load}\\ I_{bref} -\end{cases}\\ \text{Diesel Generator} \rightarrow \text{Able to supply power to the load}\\ \text{BTS Load} \rightarrow \text{inactive}\end{cases}$$

3. FUZZY CONTROLLER OF HYBRID ENERGY SYSTEM FOR BTS SITE

Energy sources of hybrid system are controlled at optimal level by using fuzzy controller. This control scheme determines the operation mode [2] of each generation sub system, that is (Solar, Wind, DG). These operation modes are determined by energy balance between the total demand (BTS load and battery bank) and the total generation (Solar, Wind, DG). In this controller scheme the Wind and Solar are the main energy source and Diesel Generator acts as complementary source. The controller outputs decide signals to activate or deactivate each subsystem. The fuzzy based hybrid controller is designed

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to control the management of electrical energy supply to the BTS load from PV-Wind hybrid energy system optimally. This overall control scheme for standalone Wind, Solar and Diesel hybrid system are implemented in Matlab-simulink [12] environment.

The simulink model for hybrid system with fuzzy control scheme is shown Fig. 2 on next page.

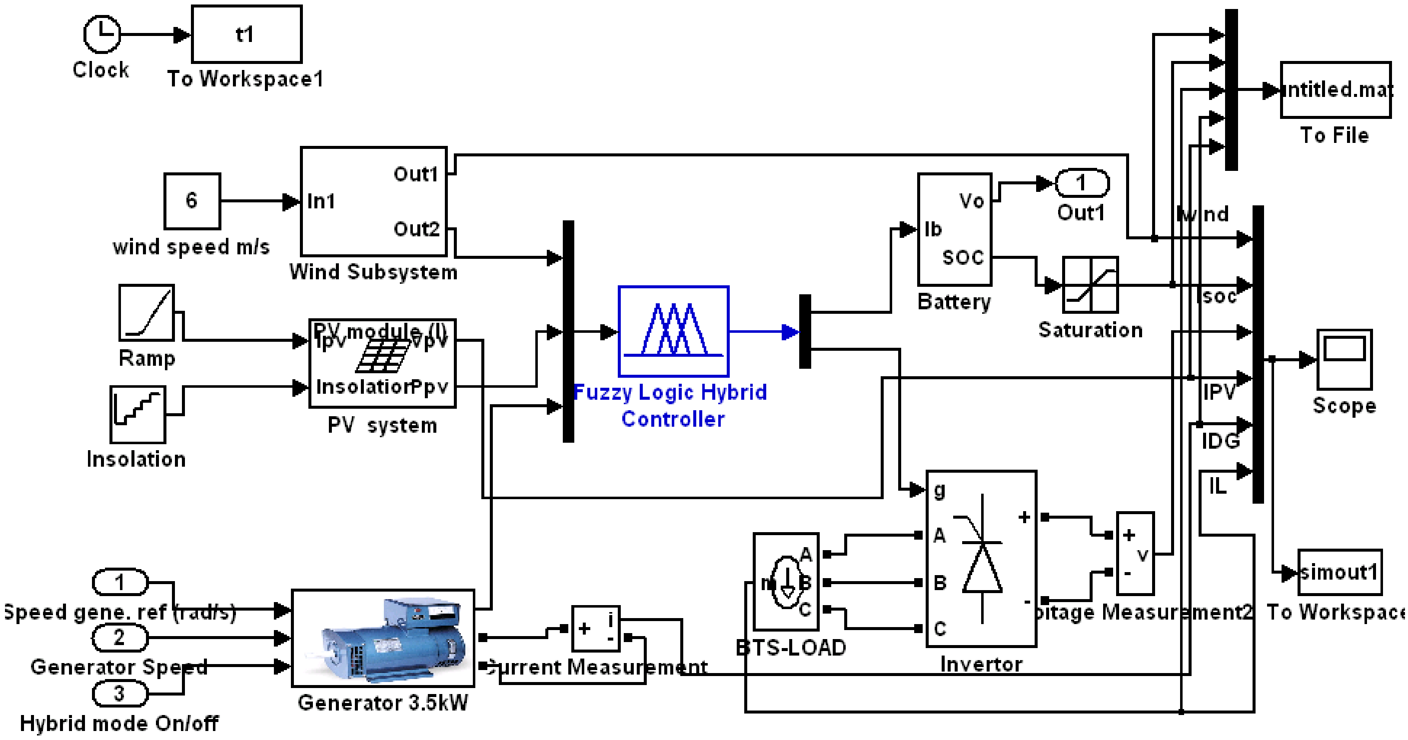

Fig. 2. Simulink model for hybrid system with fuzzy controller

- **INFERENCE SYSTEM FOR FUZZY HYBRID CONTROLLER**

The first step of designing the fuzzy controller is to develop the fuzzy inference system (FIS). It is the heart of the controller. The fuzzy inference system is used for the decision process of hybrid controller.

The general scheme of FIS for fuzzy based hybrid controller of stand alone hybrid system is shown in Fig. 3. In this controller scheme the three inputs and two outputs are considered.

Photovoltaic energy conversion system (PVES), wind energy conversion system (WES) and diesel generator are the input variables. BTS load and battery bank are output variables.

For this fuzzy based hybrid controller the inputs are characterized by generalized bell shaped membership function and outputs are characterized by triangular membership functions.

These membership functions are defined by:

PS- Positive small,
PM-Positive Medium,
PB-Positive Big, Z- Zero,
N-Negative,
NS-Negative small,
NM-Negative medium,
NB-Negative Big.

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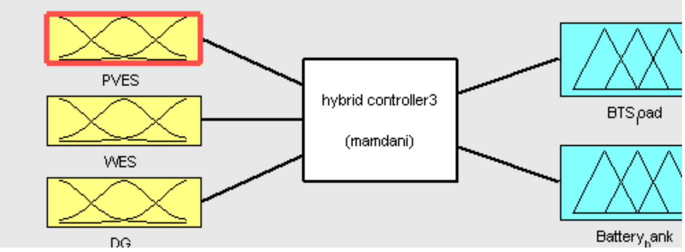
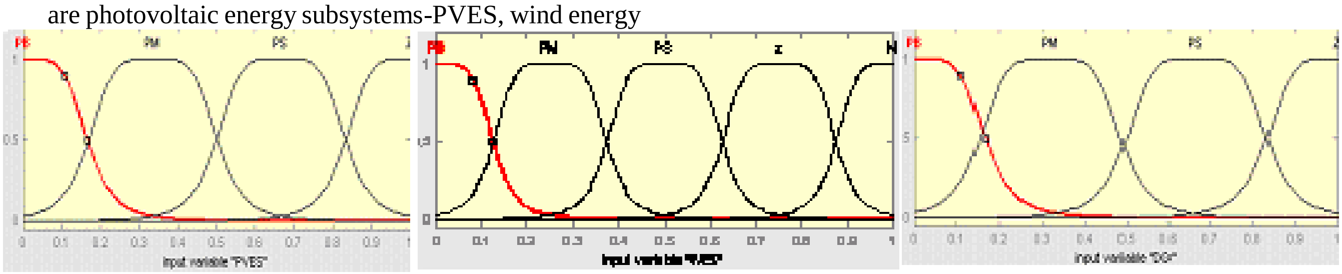


Fig.3. Fuzzy hybrid controller with 3 inputs and 2 outputs

1) *Input Variables:* The input variables of fuzzy controller are photovoltaic energy subsystems-PVES, wind energy subsystem, operation of diesel generator-DG. All inputs are characterized by Gbell shaped membership functions shown in Fig. 4. These inputs variables are described by different membership functions, which are PB, PM, PS, Z, N. these are defined as per power regulation, maximum power tracking, active and inactive mode of operation of hybrid controller. The universe of discourse is taken 0 to 1 for each input variables.



(i) Photovoltaic Energy System (ii) Wind Energy System (iii) Diesel Generator

Fig.4. Membership functions of input variables for fuzzy hybrid controller.

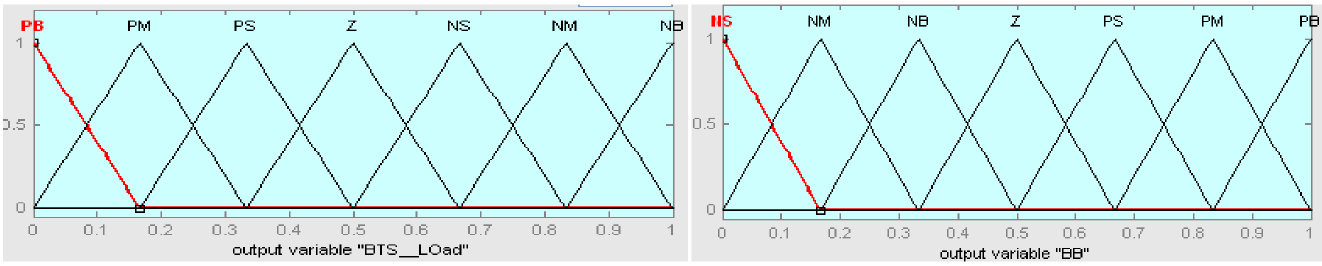


Fig.5. Membership functions of output variables for fuzzy hybrid controller

2) *Output Variables:* The outputs of fuzzy controller are BTS load and state of charge of battery bank. The membership functions of outputs variables are decide according to the state of charge of battery bank and back-up capacity of BTS System. The universe of discourse for battery bank and BTS load is defined as per storage capacity. The membership functions of output variables BTS-load and Battery bank are shown in Fig. 5.

3) *Fuzzy Rule Base:* To implement conventional fuzzy rules, an input space is divided into many fuzzy subsets according to mode of operation. The fuzzy subsets are the combination of fuzzy rules. The fuzzy if-than rules of the hybrid controller are depending on the membership function of different input and output variables are shown in Table-1 here as under.

TABLE I
FUZZY RULE BASE TABLE

P_{Wind}	P_{Solar}	P_{DG}	$P_{BTSLoad}$	P_{Bat}
PB	Z	NB	PB	NB
PM	PS	NM	PM	NM
PS	PM	NS	PS	NS
Z	PB	Z	PB	PB
N	PS	PS	PM	PS
PS	PM	PM	PS	PM
PM	PB	NB	Z	PB

The energy management strategy, described in terms of linguistic term, is implemented by 130 fuzzy rules, according the mode of operation. In order to include fuzzy sets for solar and wind subsystem, BTS site load demand, allowable diesel generator feeding power and state of charge (SOC) or discharged ampere-hour by battery.

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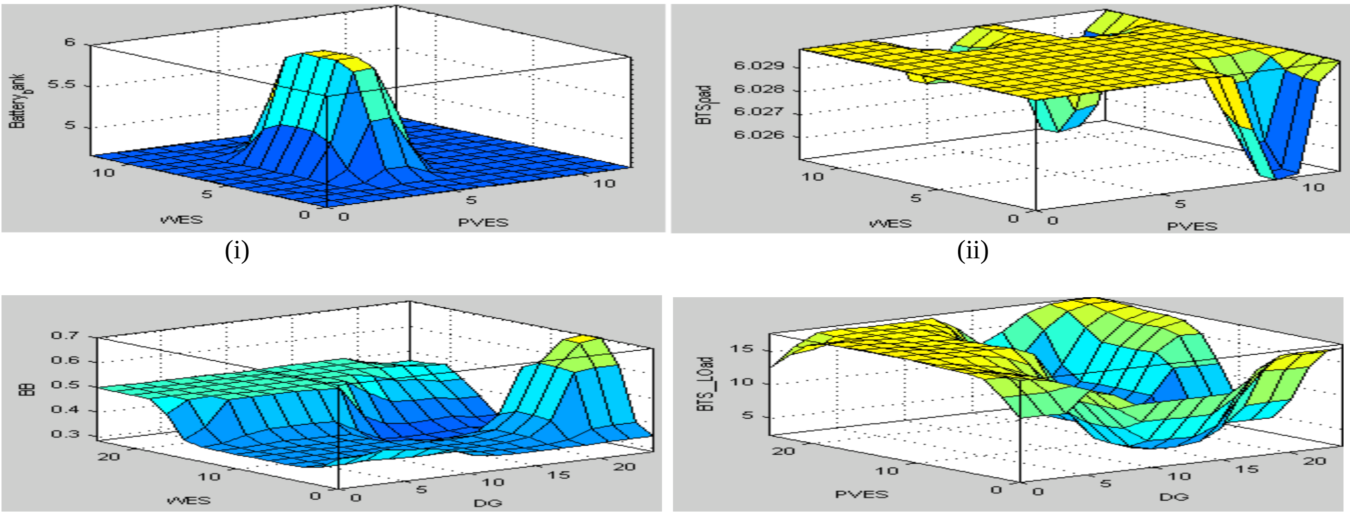
The rule base is written considering the following possible criterion scenarios in an operational BTS system:

- Energy supply to the BTS load by solar and wind subsystem.
- Diesel operating strategy to reduced the start-stop cycles
- Evaluating the battery SOC
- To manage the charge-discharge operation of battery

Considering the one thirty rules for accomplishing the different mode of operation of fuzzy controller, these rules are shown in Fig. 6.

The Fig. 6(i) Rule Viewer is showing results with battery operation and Fig. 6(ii) Rule Viewer is showing results with BTS load outputs at different combination of rules.



(i) (ii) (iii) (iv)

Fig.6 . Surface Rule view for hybrid controller (i) with battery (ii) with BTS load at different inputs.

4. SIMULATION RESULTS

The simulation result gives the different currents when the battery bank is fully discharged. Fig. 7(a) shows the wind current, which, in this case, is the complementary generation source.

Note that there is a time delay in between, when the wind turbine starts delivering energy to the system and when the generation command is given.

Fig. 7(*b)* is the PV array current. In this case, it is in the main generation role, so it is always operating at MPOP(maximum power operating point) to satisfy the demand. Fig. 7(*c)* is the battery bank current.

Fig. 7(d) is the diesel current. While the turbine starts, the deficiency in generation is supplied by the battery and the diesel generator.

Fig. 7(e) is the total demand current.

Fig. 7(*f)* shows the operation mode for the fuzzy controller

5. CONCLUSION

This paper presented the performance of a hybrid energy system controlled by a fuzzy controller, capable of managing all the energy resources of the system. The results presented on the previous section, demonstrated that the designed control is capable to determining the operation mode of each subsystem presented on hybrid energy system. To accomplish the different control objectives (i.e., power regulation or maximum power conversion) in both (wind and solar subsystems), we use

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fuzzy control technique, for the energy management of the complete hybrid system. In this scheme, we assumed that the main generation role would be carried out by the renewable energy, i.e., wind and solar subsystem respectively, while the traditional generation play a complementary role.

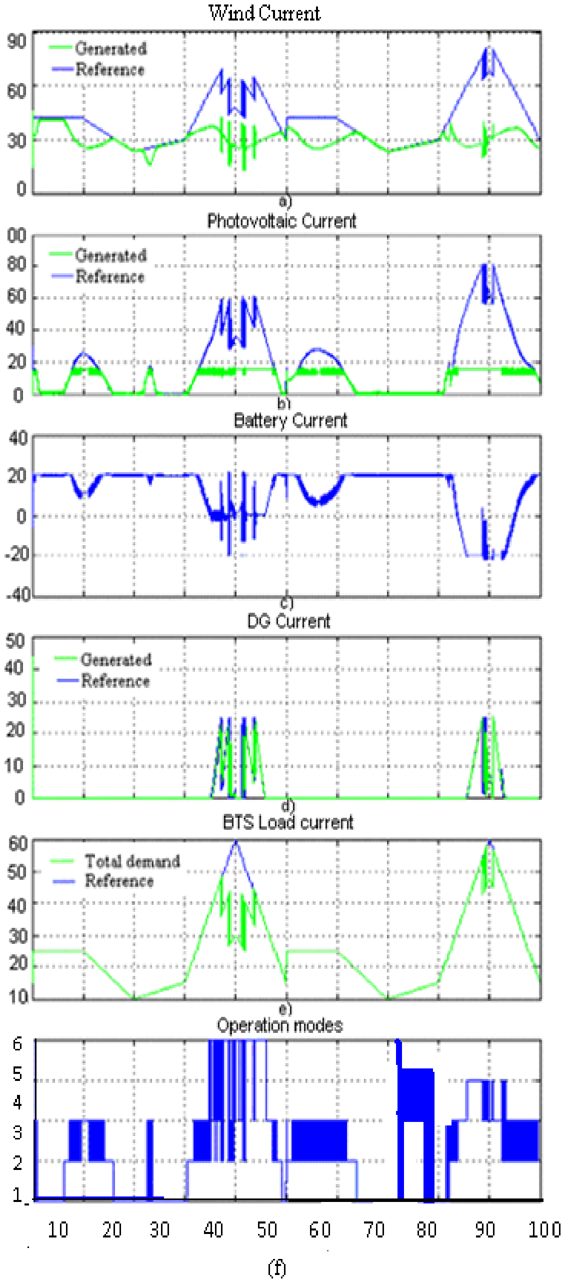

Fig. 7. DC bus current at sufficient generation

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