An Intelligent Energy Management Frame Work using Fuzzy Logic for Grid Connected Hybrid Energy System

V. Dega Rajaji, K.Chandra Sekhar

Abstract*: India is one of the fastest growing countries in terms of energy consumption. Currently, it is the fifth largest consumer of energy in the world, and will be the third largest by 2030. The country is heavily dependent on fossil sources of energy for most of its demand. In response to present scenario of energy consumption, India is gradually shifting focus towards its renewable energy resources. Power can be delivered at maximum efficiency with maximum continuity through an effective energy management system. The energy management system should effectively and efficiently manage the power exchange among different units of systems and also reliably regulate the load to ensure that the load is always supplied. This paper proposes a Fuzzy Logic based optimal energy management Strategy for complex systems that comprises of PV Energy System, Wind Energy System, Fuel Cell and a Battery. The performance of the proposed approach is evaluated by simulation in different operating conditions. To this purpose some performance indexes are considered, such as: the frequency deviation, the stability of the DC bus voltage and the AC voltage total harmonic distortion.

Keywords: Fuzzy logic, PV, Wind, Fuel Cell, Energy Management

I. INTRODUCTION

Energy has become an essential commodity and the Smart Management of energy distribution is very essential. There are different mixtures of fuel which supply this required energy and the growth index of any Country is influenced by its Energy needs and how the needs are satisfied. The concern about the climate changes and the necessity to shift from conventional sources of energy has underlined the importance of Renewable Energy to meet the future energy needs. Inspite of concerted efforts to push for Renewable Energy close to 57.3% of the total electrical production in India is from Coal based Thermal Power Plants [1]. Inspite of India's obligation to the Parry's climate accord the contribution of Thermal Power Plants in energy production is expected to fall to 48% only by the Year 2022[1]. This underlines the work that has be done in regard to augmenting the energy production and management from the Renewable Energy Sources. There are three technologies that are contributing the push towards the clean energy. The foremost and most abundant energy sources are Solar Radiation [2, 3]. The second in the list is Wind energy that has completely taken advantage of reduction in cost of Wind Generator Technology. The cost of Wind Power in India is as low as Rs.2.44 per unit [4, 5]. Another evolving and much researched about Renewable Energy sources is fuel cell Technology. Even though there is no wide spread implementation of fuel cells especially in commercial power production. Fuel cells are the way forward to meet the future energy needs. [6].

The full exploration of these energy sources can only be accomplished with the help of suitable energy storage systems. The combination of these four namely the Solar, Wind, Fuel Cell with a suitable energy storage mechanism can potentially used for both grid connected as well as standalone hybrid generation systems. In both these cases it is imperative to do the system management to control the generators suitably so that power can be delivered at maximum efficiency with maximum continuity of load supply and minimum interruptions. In case of the grid connected system the objective is to inject more power into the grid while drawing less power from the grid. In order to achieve this, an energy management system is very much essential. The energy management system should effectively and efficiently manage the power exchange among different units of systems and also reliably regulate the load to ensure that the load is always supplied.

This paper proposes a Fuzzy Logic based optimal energy management strategy for a complex system that comprises of PV Energy System, Wind Energy System, Fuel Cell and a Battery. The complexity of the system is further compounded by the fact that it is connected to the grid and can inject (or) with draw power from the grid.

The inputs that are considered for the power management strategy are net power (P-Net), DC Bus Voltage (VDC), Battery State of Charge (SOC) and normalized Hydrogen Tank Pressure of the Fuel Cell. These four serves as inputs to Fuzzy Logic based management system that insures the operation of different units like charging and discharging of Battery, running the Electrolyser, Supplying the power to the grid (or) withdrawing the power from the grid.

The system is configured to draw power from the grid only

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under extreme contingency where both the fuel cell and the battery can't supply the load. The primary objective for the control strategy is to identify the references for the several of sub-systems in the hybrid generation unit.

II. POWER MANAGEMENT STRATEGY

A. SUB-SYSTEM

The schematic of proposed hybrid generating system is depicted using Fig. 1. The three primary components like PV, Wind and Fuel Cell are supposed to controlled by three independent and individual control systems. In the case of PV Cell the MPPT is achieved by a GA-ANN based MPPT algorithm as discussed in [7]. Similarly the MPPT of Wind energy is obtained using ANFIS based model as explained in [8].Whenever there is excess of power even after the battery is fully charged and the hydrogen tank is at full pressure, it is supplied to grid. In order to generalize the analysis the system sizing is must included in the scope of the paper. The important details of the sub-system have been tabulated using Table-I.

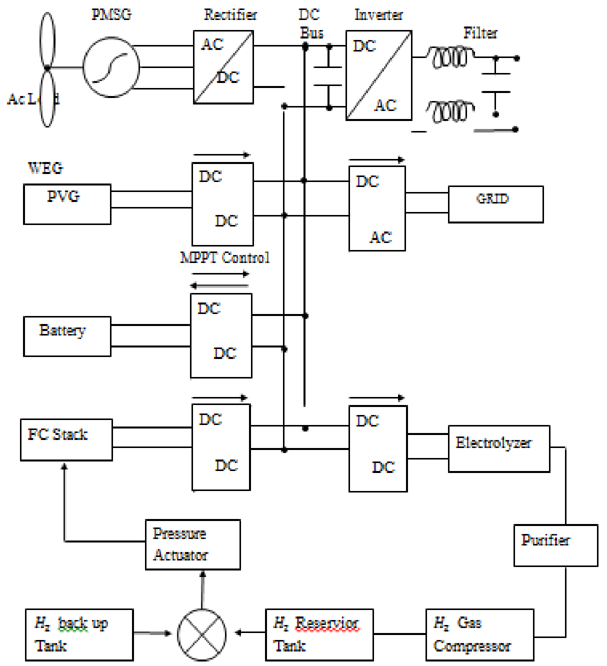

Fig. 1 Proposed hybrid generating system

Table-I Details of sub system

PVG AND WEG MAIN DATA			
PVG		*WEG*	
Module model	Solyndra® - SL001 - 157	Model	TN-1.5 Nozzi Nord
Module unit	157W_p at STC	Rated power	1.5k W
Module open circuit voltage	92.5 V	Cut in/Cut out speed	4m/s & 20m/s
Module number	3 x 4 =12	Generator type and ratings	1.5kW PMSG @ 50H_z
Power rating	1.88kW_p		
FC STACK AND ELECTROLYZER MAIN DATA			
FC Stack		*Electrolyzer*	

Model	Nexta™ (PEMFC)	Model	Von hoerner
Rated power	1.2Kw	Rated power	2.25kW
Operating voltage	22-50V	Voltage range	30-100V
Temperature range	3˚C	Battery(lead acid)	1k W_h at 96V

B. CONTROL STRATEGY

The primary input is the evaluation of the net power (P-Net). The net power is compiled by adding up the power generated by the PV and Wind Energy Systems and subtracting the power required by the load.

$$PNet = PPV+PWEG-Pload$$

PPV and PWEG are the power generated by the PV Systems and the Wind Energy Systems while Pload is the load power. Excess (or) deficiency of PNet suitably determines the plant operational mode whenever there is excess power ie, the net power is positive, the excess power used to charge the battery.

When the battery is fully charged and net power is continuous to be positive the excess power is used to run the electrolyser of the fuel cell. If both the battery is fully charged and the electrolyser tank (H2) is at full pressure then the excess power is supplied to grid.

If PNet is negative the fuel cell stack is turned on followed by switching on the battery and if the net power continuous to remain negative then the power is withdrawn from the Grid to compensate the shortage.

III. FUZZY LOGIC CONTROL

The Fuzzy Logic Control effectively accomplishes the management strategy depicted using figure(2). The Fuzzy Logic has been implemented using MATLAB Fuzzy Logic tool box and mandani Fuzzy Logic inphase has been used for accomplishing the control strategy. The primary advantage of using Fuzzy Logic Control is that the linguistic description in Fuzzy Logic avoids the necessity to use the detailed model for both the control systems as well as the control strategy [9]. There are four inputs that are considered to manage power distribution as illustrated in Table-II

Table II- Input variables for the fuzzy system.

S.No	Input Variable
1.	Net Power(P_{Net})
2.	Bus Voltage(V_{DC})
3.	Battery State of Charge(SOC)
4.	Normalized Hydrogen Tank Pressure

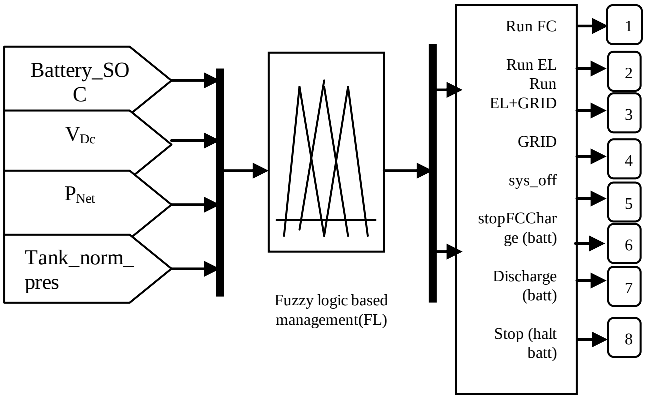

Fig.2 The energy management system

The inference system has been depicted using fig.3.

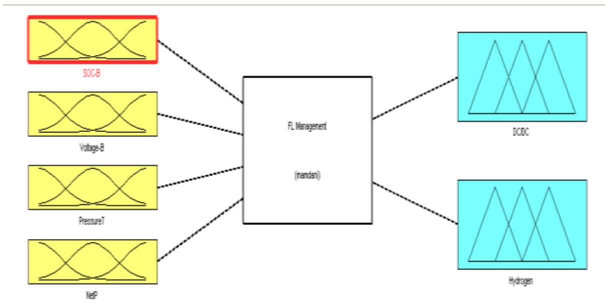

Fig. 3 Interference system

There are two membership functions that are used for mapping the range of input variables. For net power, DC bus voltage(Vdc) and battery State of Charge trapezoidal membership functions is used where as for normalized hydrogen tank pressure a triangular membership function is used. Linguistic classification is used for these parameters. For example: the battery SOC and the normalized hydrogen pressure tank is divided into three categories namely " empty", " medium" and " full" as represented using fig.4. The inference system has been depicted using fig 4.

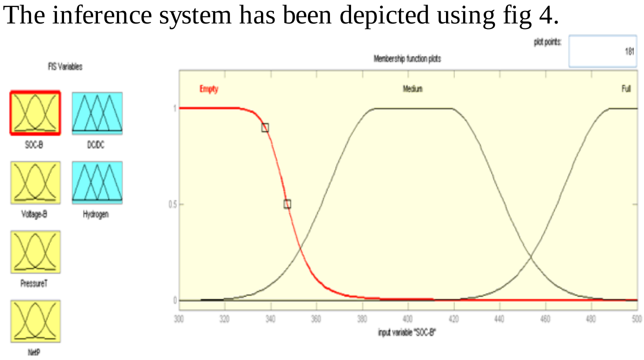

Fig.4 Membership function plot representing batter state of charge

The antecedent dc bus voltage is categorized into low limit, normal limit and high limit. Similarly the antecedent of net power is categorized into five zones-small deficit, normal deficit, high deficit, normal excess and high excess as represented using fig.5.

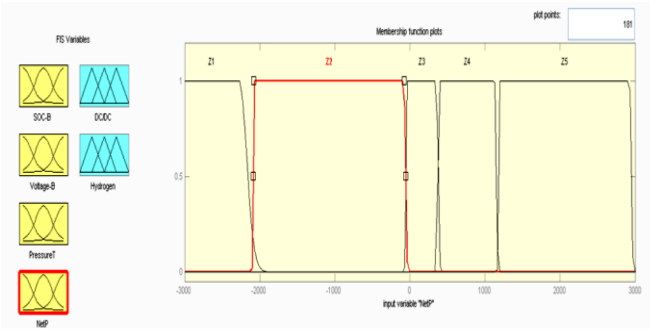

Fig.5 Membership function plot representing net power

Similarly triangular membership functions are used to start the fuel cell, electrolyser, supply the grid and withdraw from the grid as represented using fig.6.

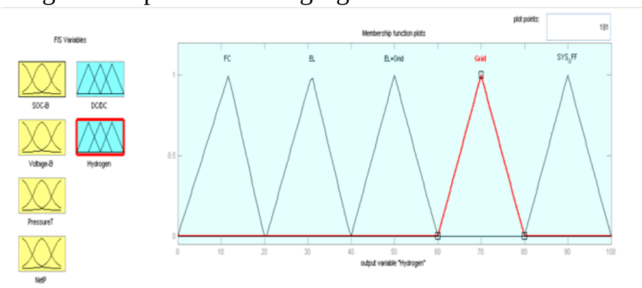

Fig.6 Membership function plot representing the output control

IV. RESULTS AND DISCUSSIONS

In order to evaluate the Fuzzy Logic based management system three cases are considered. In all the three cases the power flow and load demand is expressed in per unit system at base value of 1 KW. The dc bus voltage is normalised at 400V, the voltages are seem to be varying between 370 V-430V. the normalised frequency deviations is also computed as one of the performance measure where the grid frequency is assuming that 50HZ. Similarly Total Harmonic Distortion is also computed to evaluate the quality of output of AC Voltage. In order to evaluate the performance the time domain simulations have been carried out for 240 Seconds.

A. CASE I

In this case the net power is in excess and the battery is assumed at full charge at t=0 sec. The time domain specifications is done at 4 intervals 0-60s, 60-120s, 120-180s and 180-240s.The attributes of simulation are provided using table-III.

Table III: Simulation attributes for Case -1

S.NO	Time Interval	Maximum sustained Wind Speed (m/s)	Solar Radiation (PU)	Average load power (PU)	Net Power (PU)
1.	0-60 sec	8.5	0	0.55	0
2.	60-120sec	11	0.85	0.75	2.5
3.	120-180sec	11	1.055	0.2	3.1
4.	180-240sec	9	0.5	2	-2.2

For this the normalized frequency deviations were observed at a maximum of 0.18 as illustrated using fig.7 and Total Harmonic Distortion (THD) was observed to be 0.036, the dc bus voltage was observed at 0.9763PU.

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The plot of THD is depicted using fig.8 and the voltage profile for this case is depicted using fig.9

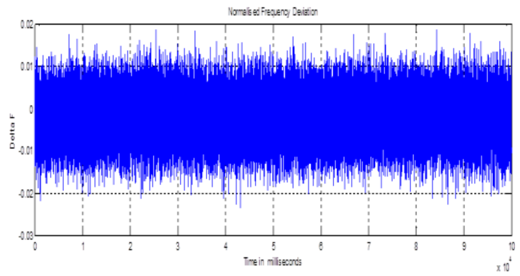

Fig. 7 Normalised frequency deviation for simulation of Case - I

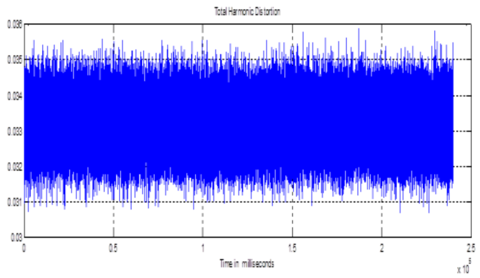

Fig.8 THD for simulation of Case – I

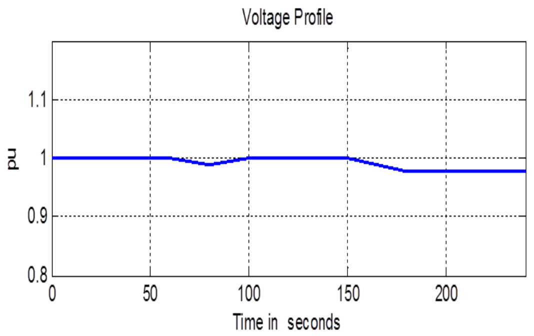

Fig.9 Minimum voltage profile observed for Case 1

In this case during 60 seconds to 120 seconds According to the developed power management strategy, the excess power is delivered to the electrolyzer. Therefore, the storage tank normalized pressure increases as the hydrogen is pumped in. Similarly during 120 -180 seconds interval The excess power in this interval is higher than the electrolyzer rated power so a part of energy produced is delivered to the grid and storage tank normalized pressure increases as the Hydrogen is still pumped in. During the last interval the power lack is compensated by the batteries according to power management strategy.

B. Case-II

In this case deals with scenario where there is insufficient power generator. The simulations are carried out for four intervals. The attributes of simulation are provided using Table-IV.

Table- IV: Simulation attributes for Case -2

S.NO	Time Interval	Maximum sustained Wind Speed (m/s)	Solar Radiation (PU)	Average load power (PU)	Net Power (PU)
1.	0-60 sec	5	0.25	0.55	0.15
2.	60-120sec	6.8	0.55	1.65	-
3.	120-180sec	8	0.55	0.45	-
4.	180-240sec	11.5	0.55	1	-

For this case also the normalised frequency deviations was observed at a maximum of 0.18 and Total Harmonic Distortion was observed to be 0.036, while the dc bus voltage was observed at 0.952PU as depicted using fig.10. In this case during the first interval since the power lack is small it is compensated only by the batteries. During the second interval the lack of generated power increases. FC/E-ESS covers the difference while the power drawn from batteries is null. The H2 storage tank pressure decreases as the H2 is pumped out. During the next test interval of 120 seconds to 180 seconds the excess power is transferred to the batteries. During the last test interval the WEG supports all the load demand.

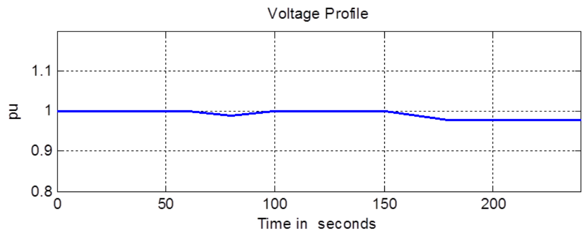

Fig.10 Minimum voltage profile observed for Case 2

C. Case-III

This scenario considers that the power generated from the Wind and PV System are both 0 so that the net power is deficient throughout the simulation. The simulation is carried out into 3 intervals 0-60s,60-120s and 120-180 s. In the first interval the load is assumed to be 0.3PU In the second interval the load is assumed to be 1PU and In the third interval the load is assumed to be 0.25PU.Similarly in case-II similar results were observed. The only deviation was in regard to voltage profile for case-III the minimum voltage profile was observed at 0.916 pu as depicted in fig.11.During the second interval as per power management strategy FC covers the lack power during those periods, while the power drawn from batteries is less than 0.1pu just to maintain the DC bus voltage in the designed range. The H2 storage tank pressure decreases as the H2 is pumped out. In other intervals the power demand is compensated by the batteries.

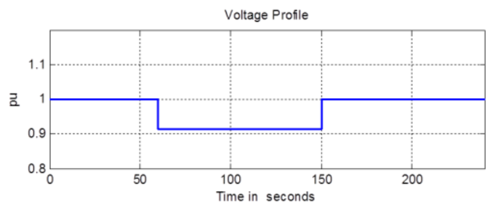

Fig.11 Minimum voltage profile observed for Case 3

V. CONCLUSION

The Fuzzy Logic based energy management system has been proposed and implemented for an Hybrid system comprising Solar, Wind and Fuel-Cells. The proposed Control strategy which bases its decision on excess (or) deficient power augurs for an efficient power management strategy. The proposed approach is devoid of any complex mathematical models and can provide optimize energy distribution. Similarly the time domain simulations verify and validate the efficiency of proposed system as identified by the different metrics like normalized frequency deviations, Voltage Profile and Total Harmonic Distortion.

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