Energy Management Control System for Hybrid Renewable Energy Power Sources

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Abstract. Ethiopia is a developing country, where population living in the country side still does not have access to electricity – for the most part. The majority of the population in the rural areas uses fossil fuels for house hold use. Fossil fuels are friendly to the environment. Renewable energy sources are alternative solutions to mitigate these problems. Ethiopia is endowed with numerous renewable energy resources naturally. The major ones are small-scale hydropower, biomass, and solar power. This paper deals with the design and implementation of a hybrid power generation energy management system to be used in the Benti rural village of Fogera Wereda. Managing the different energy sources is discussed in detail. The Fogera site consists of 426 households with a total electric power demand of 120 kW. To satisfy this demand, 50%, 30%, and 20% are to be contributed from hydro, solar, and Biomass power system generations respectively. A fuzzy logic controller is used as the main component of the power management system. The controller monitors the demand coming from the loads and which sources are available to switch to the appropriate power supply regularly.

Keywords: Hybrid · Solar · Biomass · Hydropower · Fuzzy logic controller

1 Introduction

Ethiopia is naturally gifted with several renewable energy sources which can be used as a source of electrical energy. A few of the major ones are hydropower, biomass, wind, and solar energy which can be utilized separately or in combination. Be that as it may, conventional biomass energy is the overwhelming source of energy within the country range for about 83% of the full population of Ethiopia [1]. Village electrification may be a pivotal step for moving forward the socio-economic conditions of provincial zones and by and large advancement of the nation [2]. The nation includes a gigantic renewable vitality potential that has not yet been evaluated for rural charge. In case country communities are provided with cutting edge power from renewable vitality assets, the vitality utilization of the nation increments and after that the business of its populace will be moved forward. Nonetheless, there are many adverse effects of continual use of traditional biomass energy, such as the continuous deforestation, the scarcity of natural resources and the rising cost of household fuels. In particular, the

M. L. Berihun (Ed.): ICAST 2021, LNICST 412, pp. 464–479, 2022.
https://doi.org/10.1007/978-3-030-93712-6_31

gathering of firewood has increased the physical strain on the women and children usually entrusted with this task; and rising oil import costs have hurt Ethiopia's trade balance and caused a shortage of foreign exchange (Fig. 1).

Fig. 1. Lack of electricity accesses and its consequences in rural village (Source: Fogera woreda city administration)

In order to mitigate those problems, the worldwide attentions are given to renewable energy technologies. Connecting the majority of rural areas to the main electrical grid requires a huge investment and effort. The micro-grids can be a cost-effective solution for such rural areas. Through previous work, researchers have attempted to combine and hybridize different energy sources. Siddhartha Gobina [3] proposed an optimal sizing based on a genetic algorithm of an autonomous hybrid solar battery/biomass power supply system to meet the energy demand of a typical village on Sagar Island. Melakou. M [4] developed a hybrid renewable energy generation based on a fuzzy logic controller for the village of Barsoma. rural districts in Ethiopia. J. P. Sharma [6] proposed an autonomous hybrid energy system model for universities. Martin Galad et al. [7, 10, 11] discussed a module design of photovoltaic solar cells for an autonomous renewable system. However, their work was only based on the design and modeling of the hybrid power systems. Hybrid power systems need to be controlled depending on the power demand and energy resource availability of the village. This paper introduces the hybrid power system management based on the fuzzy logic controller. The fuzzy logic is responsible to switch the available power system sources depending on the power demand. In this work, storage systems (Batteries) are not considered, due to cost factor. This research focuses on AC power systems, which is generated from hybrid energy sources and how it is controlled to meet the power demand.

2 The Proposed Hybrid System

The proposed hybrid system combines solar, micro-hydro and biomass renewable energy sources as shown in Fig. 2. Its ability to meet energy demand depends on climate data, area location and household size. These conditions will determine the different operating modes of the system. The controller is responsible for meeting customer energy demands and improving system efficiency. The controller detects the demand on the load side and switches the source accordingly to meet the demand on the customer side based on the availability of energy resource.

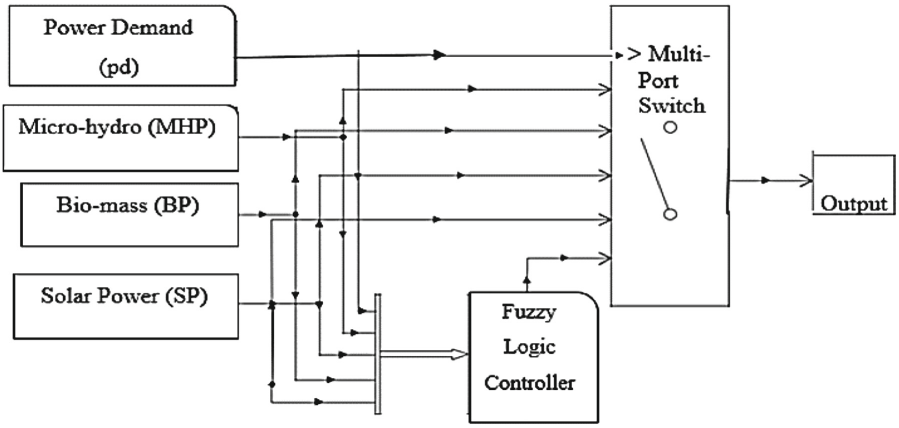

Fig. 2. Block diagram of proposed hybrid system

In principle, these techniques are evaluated by the energy balance between total production and total demand. A full-fledged controller is essential to efficiently manage the operation of production subsystems. It depends on the amount of load; the controller makes the appropriate decision to switch the multiport switch to the desired load demand output.

3 Energy Demand

Evaluation of the total energy consumption of the study area is the first step taken to design an electric power system [4]. The size and cost of implementing hybrid system components is strongly influenced by the size of the electrical load. Determination of village load was carried out for 426 families with an average of four members per family unit; representing a population of 1704 (source: the city administration). Load estimation is carried out by identifying the type, daily operating hours, number of equipment and their evaluation. As a result, the total energy consumption is estimated using the general formula;

$$\text{Energy consumption(kWh)} = \text{number of appliances used} * \text{power rating of each appliance (W)} * \text{hours of operation}/1000.$$

Energy demands in the village is estimated by assuming the following uses for the average household: lighting (100% of population), 4 water pumping motors for irrigation, Radio (70% of population), TV (70% of population), household refrigerator (25% of population), cooking stove (10% of population), and Injera Mitad (7% of population). Due to the high energy demand of Injera Mitad and cooking stoves, the number of users is small. The elementary school (10 lighting each consuming 130w, 8-fluorescent lamps each consuming 52 W, one copy machine consuming 900 W, and one computer consuming 300 W,) and clinic (8 lighting each consuming 104 W, 4 fluorescent lamps each consuming 26 W, one vaccine refrigerator consuming 100 W, microscope consuming 15 W, water heater consuming 1000 W, and one computer consuming 30 W) are considered as loads as shown in Table 1. Load profiles for each village were available due to the courtesy of the administrative officers of Fogera Wereda and Benti Kebele combined with the observed previous trends from similar villages that had recently been electrified.

Table 1. Total energy consumption of Benti village.

Time	Total Load (kWh)					
	Energy Household	Public loads	Energy In church	Energy in clinic	Energy in school	Total load Energy
0:0-1:0	10.65	-	0.026	0.126	-	10.802
1:0-2:0	10.65	-	-	0.1	-	10.75
2:0-3:0	10.65	-	-	0.1	-	10.75
3:0-4:0	10.65	-	-	0.1	-	10.75
4:0-5:0	16.188	-	-	0.1	-	16.288
5:0-6:0	105.222	-	0.134	0.1	-	106.122
6:0-7:0	108.63	-	0.134	0.1	-	108.864
7:0-8:0	44.73	-	-	0.1	-	44.83
8:0-9:0	44.73	9.5	-	1.115	-	55.345
9:0-10:0	44.73	9.5	-	1.415	-	55.645
10:0-11:0	44.73	-	-	0.4	1.2	46.33
11:0-12:0	44.73	-	-	0.1	0.300	45.13
12:0-13:0	108.63	-	-	0.1	-	108.73
13:0-14:0	44.73	-	-	0.1	-	44.83
14:0-15:0	44.73	9.5	-	1.115	0.3	55.645
15:0-16:0	44.73	9.5	-	1.415	0.3	55.945
16:0-17:0	44.73	-	-	0.4	0.9	46.03
17:0-18:0	44.73	-	0.080	0.1	-	44.91
18:0-19:0	136.32	-	0.184	0.204	0.182	136.89
19:0-20:0	72.42	-	0.160	0.204	0.234	73.018
20:0-21:0	72.42	-	0.026	0.152	0.104	72.702
21:0-22:0	57.51	-	-	0.152	0.052	57.714
22:0-23:0	21.726	-	-	0.126	0.052	21.904
23:0-24:0	10.65	-	-	0.126	-	10.776
Total load Energy	1199.616	38	0.744	8.085	3.624	1250.069

(Source: Fogera woreda city administration)

The total daily electricity consumption by households, commercial expenses (health centers, churches, schools) and general expenses are 1199,616 kWh, 12,453 kWh, 38 kWh, respectively. The total daily electricity consumption of Benti village is around 12050.069 kWh. Figure 3 shows the total load profile of the village. Peak loads are at

7 pm, 8 pm, 9 pm as most households use lamps. The minimum load is around 22:00 to 06:00 because the energy consumption late at night is minimal. Figure 3 shows the daily load profile of Benti village.

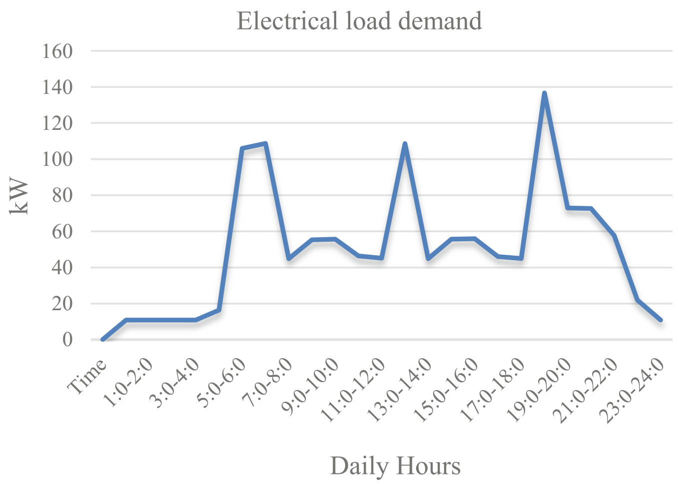

Fig. 3. Load profile of Benti village (Source: Fogera woreda city administration)

The total daily energy consumption of the selected village location is around 12050.069 KWh, and from here, the annual energy consumption is 12050.1 kWh 365 i.e., 4398275.185 kWh (4398,275 MWh). The average load demand (LD) per hour is 52.1 kW and the peak load (PL) is calculated by dividing the average load demand by the load factor (LF) and taking a load factor of 0.6.

$$PL = \frac{LD}{LF} = \frac{52.1\ \text{kW}}{0.6} = 86.8$$

Installed capacity = peak load + loss, and assuming a loss of 7% of peak load (PL) which gives 6.076 kW, the installed capacity is 86.6 kW + 6.076 kW = 92. 876 kW. Accordingly, the total electrical energy demand of the village becomes 92.876 kW.

a. **Forecasting load demand after 10 years**

The current total daily household electricity consumption is 11999.6 kWh. Consumption per household (U) = annual energy consumption (A) number of households (N).

$$U_{230} = 437.85\,\text{MWh} \div 426 = 1027.84\,\text{kWh}$$

$$\log G = 1.28 + C_1 + \ldots\ldots - K_1 \times K_2 \ldots\ldots K_N 0.155 \log u \quad (1)$$

where, G = annual percentage growth in per household consumption, U is annual kWh usage per household, C_1…. etc. are constants for household's growth (2.3%) and others. $K_1, K_2 \ldots K_N$ are constant assumed to be one.

$$\log G = 1.28 + C_1 - 0.15 \log u, C_1 = 0.05 \times PR, C_1 = 0.115$$
$$\log G = 1.28 + C_1 - 0.15 \log 1027.84,$$
$$\log G = 1.28 + 0.115 - 0.45178$$
$$\log G = 0.9432, G = 10^{0.9432} = 8.77$$

By 2030 the annual KWh usage per household is estimated via:

$$U_{230} = U_{230} \times (1 + \frac{G}{100})^{10} \div (1 + \frac{PR}{100})^{10} \tag{2}$$

$$U_{230} = 1027.84 \times (1 + \frac{8.77}{100})^{10} \div (1 + \frac{2.3}{100})^{10} = 1897.8\,\text{kWh}.$$

Number of house hold (HS) for 2030

$$HS_{230} \times (1 + \frac{PR}{100})^{10} = 426 \times (1 + \frac{2.3}{100})^{10} = 535\,\text{Households}$$

Energy consumption per household for 2030 = 1897.8 kWh × 535 = 1015.3 MWh

$$\text{Peak load demand} = \frac{\text{Annual energy consumption}}{\text{total time of the year}} = \frac{1015.3}{365} = 115.9\,\text{kW}$$

Table 2. Public and commercial loads forecast

Load type	Commercial loads			Public loads	
	Health centers	Schools	Churches	Mills	Pumps
Present condition	1	1	1	1	1
kW	0.336	0.15	0.031	1.25	0.333
Total kW	2.1				
10 years plan	1	1	1	1	2
kW	0.66	0.65	0.25	2	0.666
Total kW	4.1				

The commercial and general load needs of Benti village for the next 10 years are shown in Table 1. According to the 2020–2030 plan for the Benti village GC, the total commercial electricity demand and public load is assumed to be 4.1 kW working 10 h a day. Therefore, the total energy consumption is 4 kWh. This shows that commercial and industrial expenses will grow very rapidly due to the growth of schools, health centers, irrigation, rice production and others. Thus, the total electricity demand of Benti Village for the year 2030 is 120 kW (Table 2).

4 Fuzzy Logic Controller (FLC) for the Hybrid System

In this paper, FLC is used to monitor and regulate the power supplied by the hybrid system to electrify the village. Fuzzy logic is one type of artificial intelligence-based technique [8]. It consists of three main steps: fuzzification, fuzzy inference with knowledge base, and defuzzification which is shown in Fig. 4.

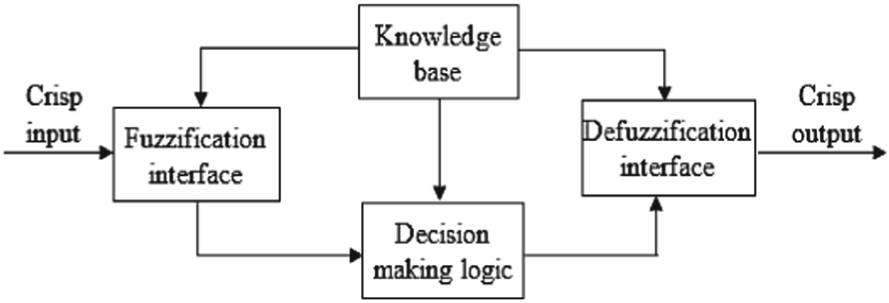

Fig. 4. The general architecture of the fuzzy logic controller [8]

Fuzzification is the process of converting crisp sets into fuzzy sets. This process is known as fuzzy inference [9]. Fuzzy inference systems come in two types: Mamdani-type and Sugeno-type which differ in the way outputs are resolved. In order for the actual system to use the output, the fuzzy logic must convert the internal fuzzy output variable to a sharp value. This conversion process is called defuzzification. Fuzzy logic design provides an effective way of controlling power systems. It first watches the load and switches the appropriate power sources to meet the demand from the costumers.

a. **Fuzzy Interface Model**

The main steps taken when designing the FLC are specifying the constraints, setting the linguistic variables, and setting rules for controllers. The fuzzy logic controller in this work has four inputs and one output. The linguistic input variables of the FLC are Solar power (Sp), Microhydro-power (Mhp), Biomass power (Bp) and Power demand (PD), and the single linguistic output variable is out power (Po). Each input linguistic variable is specified by three linguistic values namely Low, Medium and Large. The output linguistic variable has Mhp only, Mhp + Sp, Mhp + Bp, Mhp + Sp + Bp linguistic values. The fuzzy interface model in the fuzzy toolbox is developed as shown Fig. 5.

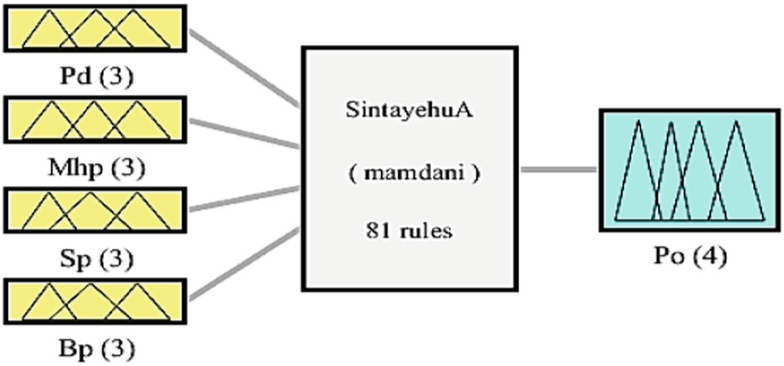

Fig. 5. Fuzzy interface model

Hence there are 4-inputs each has 3-membership functions and one output which has 4-membership functions. As a result, there are 81 fuzzy if then rules. From the total of 81-rules, 10-if then rules are shown below.

1. If (Pd is Low) or (Mhp is L) or (Sp is L) or (Bp is L) then (Po is Mhp+Sp) (1)
2. If (Pd is Low) or (Mhp is L) or (Sp is L) or (Bp is M) then (Po is Mhp+Bp) (1)
3. If (Pd is Low) or (Mhp is L) or (Sp is L) or (Bp is H) then (Po is Mhp+Bp) (1)
4. If (Pd is Low) or (Mhp is L) or (Sp is M) or (Bp is L) then (Po is Mhp+Sp) (1)
5. If (Pd is Low) or (Mhp is L) or (Sp is M) or (Bp is M) then (Po is Mhp+Sp) (1)
6. If (Pd is Low) or (Mhp is L) or (Sp is M) or (Bp is H) then (Po is Mhp+Bp) (1)
7. If (Pd is Low) or (Mhp is L) or (Sp is H) or (Bp is L) then (Po is Mhp+Sp) (1)
8. If (Pd is Low) or (Mhp is L) or (Sp is H) or (Bp is M) then (Po is Mhp+Sp) (1)
9. If (Pd is Low) or (Mhp is L) or (Sp is H) or (Bp is H) then (Po is Mhp+Sp) (1)
10. If (Pd is Low) or (Mhp is M) or (Sp is L) or (Bp is L) then (Po is Mhp+Sp) (1)

For the FLC design the triangular membership function justified the inputs; Mamdani inference system was tasked with rule processing, and center of gravity analyzed and processed defuzzification [9]. Membership function for each input-output linguistic values was assigned and the possible operational rules were generated. Next, the rules of the controller for the input values if the output were evaluated for suitability. To see the overall performance of the hybrid system, components are assumed to produce a random signal.

A) **Membership Function of Power Demand (PD)**

Membership function has three linguistic values which are Low (0 22.5 45), Medium (30 60 90), and Large (60 90 120) as shown in Fig. 6.

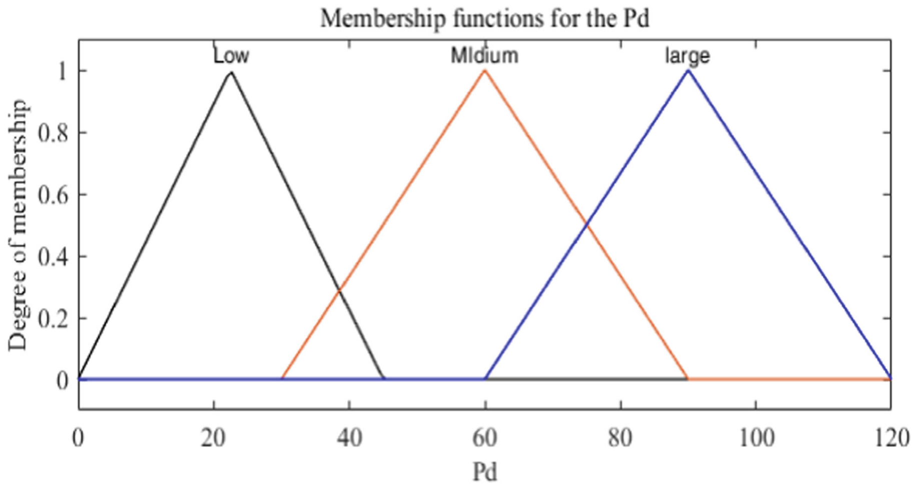

Fig. 6. Membership function of power demand

B) **Membership Function of Micro-Hydropower (Mhp)**

Mhp is the second input linguistic variable having three linguistic values: Low (0 13.5 27.5), Medium (18.3 32.08 45.83), Large (36.6 51.3 66) as shown in Fig. 7.

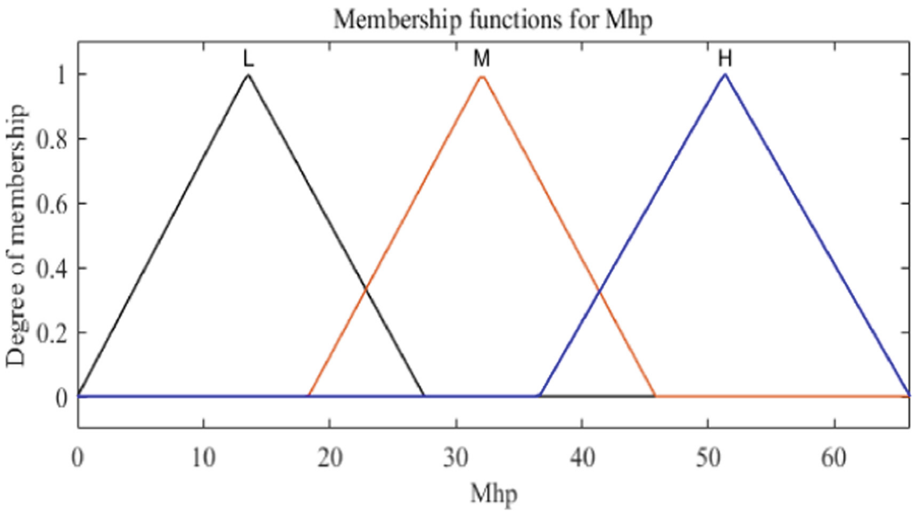

Fig. 7. Membership function of micro-hydro power

C) **Membership Function of Solar Power (Sp)**

The third input to the linguistic variable is the Solar Power which has three linguistic values, Low (0 6.66 13.33), Medium (6.66 16.67 26.67), Large (20 28 40) as shown in Fig. 8.

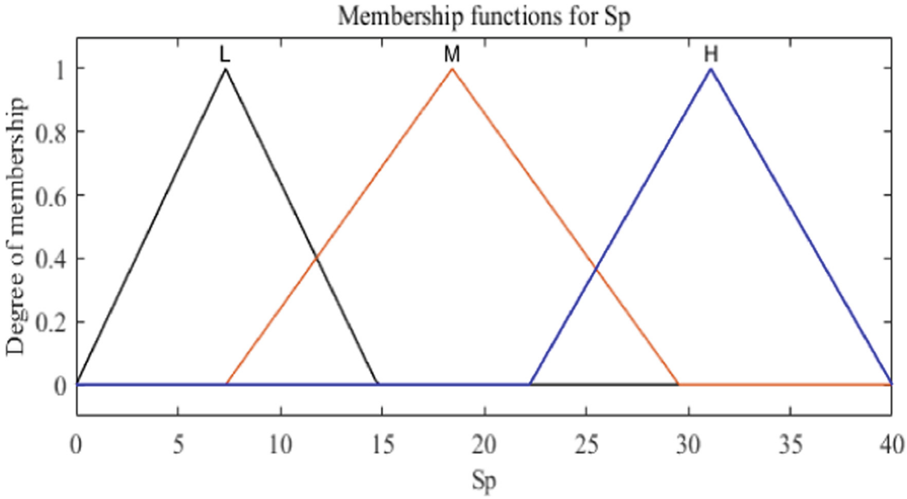

Fig. 8. Membership function of solar power

D) **Membership Function of Biomass Power (BP)**

Biomass power is the fourth input also having three linguistic values, Low (0 5 9.99), Medium (5 12.5 20), Large (15 21 27) as shown in Fig. 9.

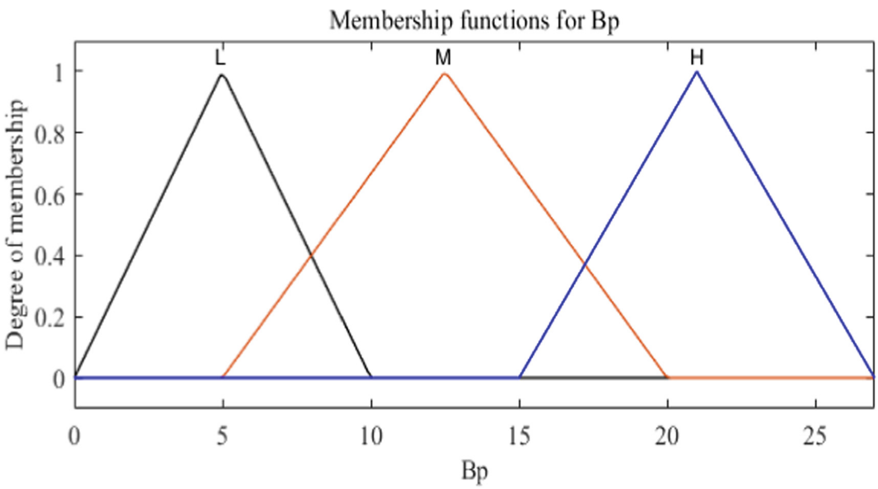

Fig. 9. Membership function of Biomass power (BP)

E) **Membership Function of Output Power (Po)**

Amongst output linguistic variables output power is the sole variable which has three linguistic values: Mhp-only (0 18.75 37.5), Mhp + Sp (30 45 60), Mhp + Bp (45 67.5 90), Mhp + Sp + Bp (75 97.5 120) as shown in Fig. 10.

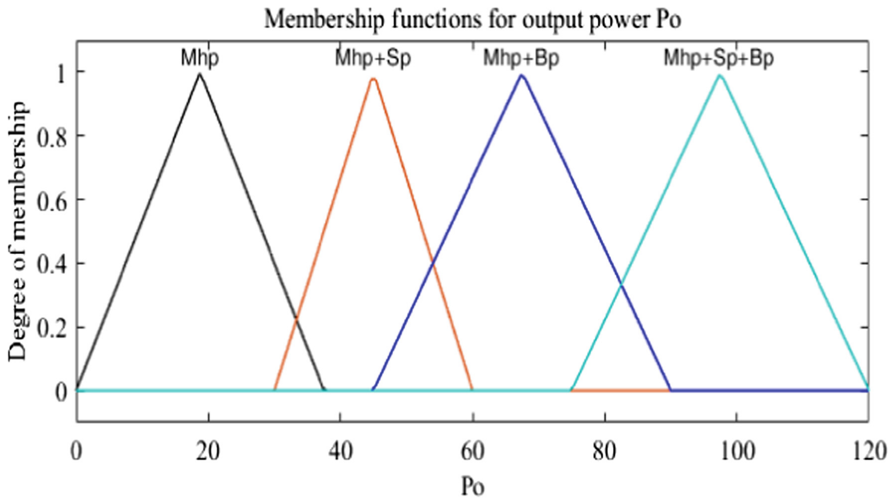

Fig. 10. Membership function of output power (Po)

The designed fuzzy logic model for the hybrid system can be seen in the 3D surface view of the model as shown in Fig. 11.

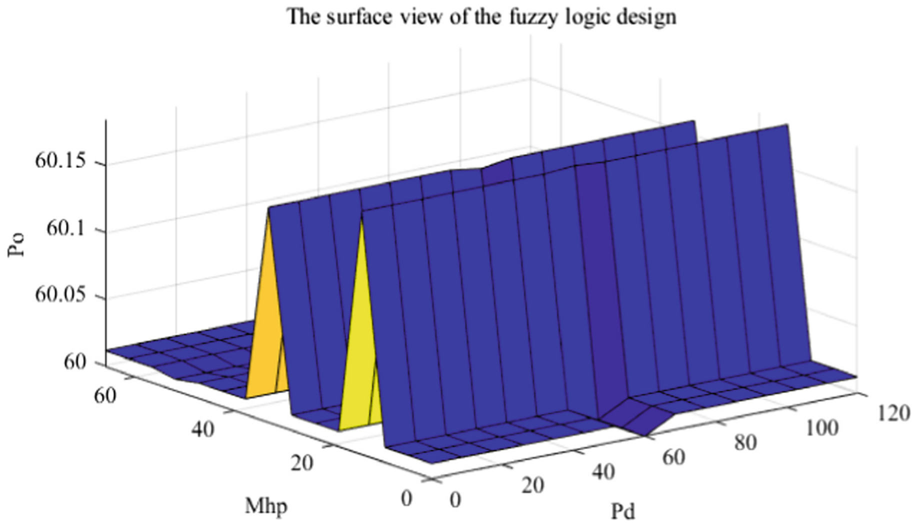

Fig. 11. Fuzzy logic design surface view

F) **Integration of the fuzzy logic controller with the forecasted model in Simulink model**

Here is a fuzzy logic controller model with four inputs and one output. The rule corpus has been written in the checkbox. The system is managed according to the established rules. Solar power (Sp), micro hydro power (Mhp), biomass power (Bp) and power demand (Pd) are the controller input parameters as shown in Fig. 12 Simulink Models. The Gaussian random signal generator is assumed to be in the form of power coming from each component of the power source. The multiport conditional switch will perform actions based on the rules coded in the fuzzy logic controller.

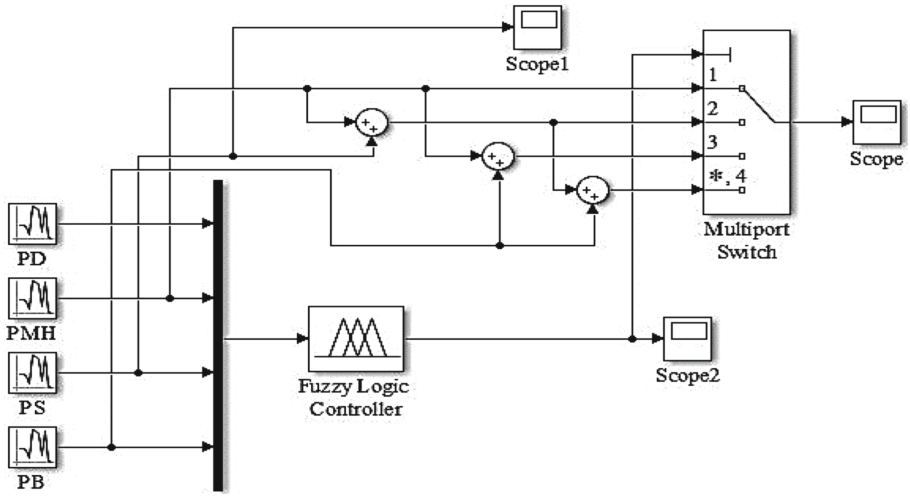

Fig. 12. The block diagram representation of the hybrid system

Since these renewable sources are discontinuous in nature, the values of all of these input sources will vary over time. To check if the controller can accommodate this variation and make the correct final decision on the multiport switch, a Gaussian random number generator is used. The generator is selected as input for these five variables (power required, micro hydroelectric power generation, solar energy and biomass energy). A couple of scenarios were hypothesized to verify the functionality of this smart controller, which are given below.

5 Simulation Result and Analysis

The designed fuzzy logic controller, is evaluated under different operating conditions, such as: whether the solar radiation is low or not, the range is high and the rice husk is medium and other conditions. However, a random number is assigned to the controller to determine the proper functionality of the controller. The scope shows the power output. This means that the output power that will provide the required power ranging from 0–120 kW,

Case Study One: If the demand power PD is 100 kW, Mhp is 60 kW, Sp is 20 kW, and Bp is 20 kW then the output power of fuzzy logic controller is given on the figure below.

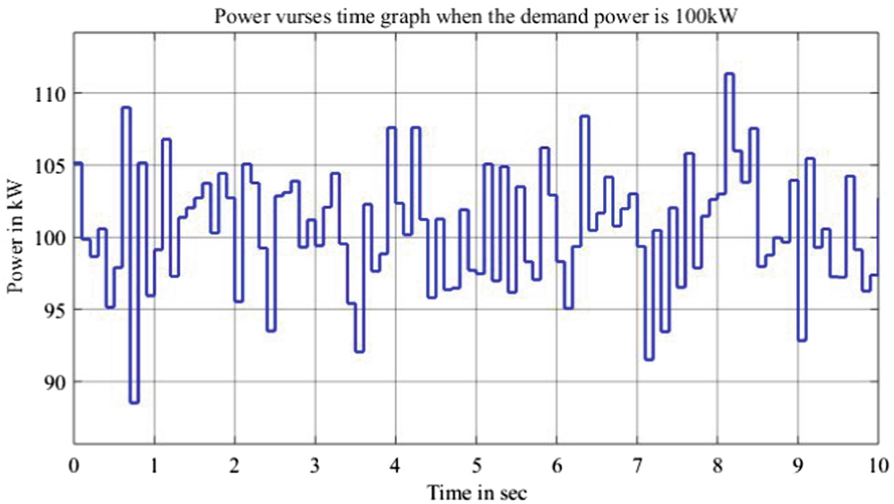

Fig. 13. Simulation result of fuzzy logic controller case one

The controller selects the power source appropriately to serve the power demand of customer. In this particular case, the power demand is about 100 kW. The available power resources will be from the respective energy sources: Mhp = 60 kW, Sp = 20 kW, and Bp = 20 kW and as illustrated in Fig. 13.

Case Study Two: If for example the power demand PD is 40 kW, Mhp = 25 kW, Sp = 15 kW, and Bp = 0 kW, then the output power is indicated as shown in the Fig. 14.

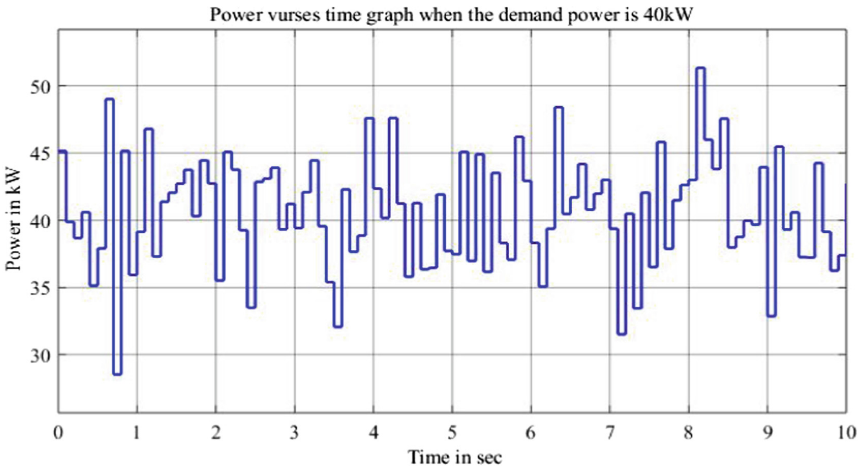

Fig. 14. Simulation result of fuzzy logic controller case two

Case Study Three: Assuming the power demand PD is 80 kW, Mhp = 55 kW, Sp = 10 kW and Bp = 15kW, then the output power of Fuzzy Logic Controller will be indicated as in the Fig. 15.

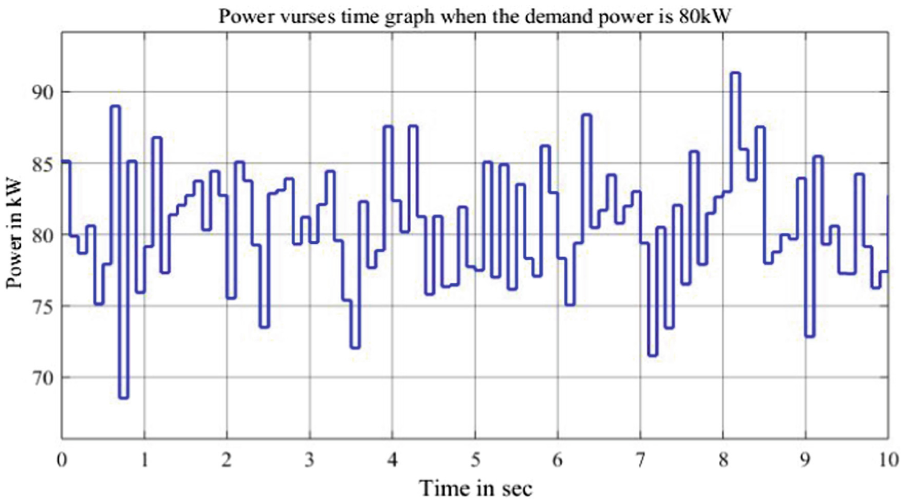

Fig. 15. Simulation result of fuzzy logic controller case three

Case Study Four: If for example the power demand PD is 60 kW, Mhp = 25 kW, Sp = 30 kW and Bp = 5kW, then the output power of fuzzy logic controller will be indicated as in the Fig. 16.

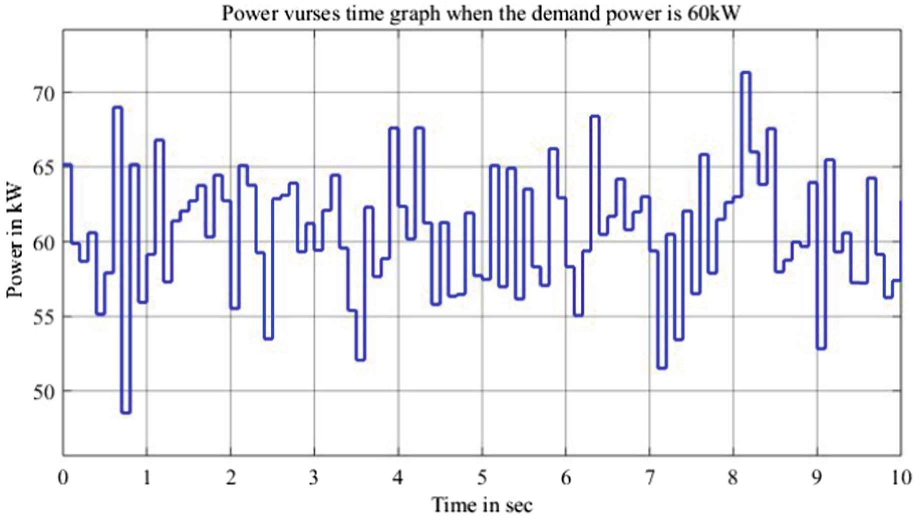

Fig. 16. Simulation result of fuzzy logic controller case three

6 Conclusion

In this paper a fuzzy logic controller is designed and implemented for a selecting a power source from a multisource electrical power scheme. This is done through the consideration of the demand from the load and the availability of the energy sources. The simulation results show that the controller can properly serve the intended power in different scenarios (the output power from controller is from 5 kW to 120 kW to satisfy the electric demand of customer). After a detailed study and analysis, we have drawn the following conclusions. The solar radiation, flow rate, and rice husk production of the Benti village are 5.4 kWh/m^2, 0.9 m^3/s, and 33.246 MT/day respectively. Load profile of the village, which consisted of about 426 households, was assessed as 1199.616 kWh, 12.453 kWh, 38 kWh per day for household applications, commercial loads, and public loads respectively. The energy consumption of the village was forecasted for 10 years using a suitable technique to be around 4398.275 MWh from 1015.3 MWh of the base year. From the load assessment survey, the total electric demand of Benti village was 120 kW. To meet this demand, the PV, Micro-hydro and Bio-mass, supply account 30%, 50% and 30% of the total 120 kW power demand, respectively. The intelligent controller makes intelligent decisions by sensing the type and amount of resource available, and then selecting—the appropriate alternative source based on the power demand.

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