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Design and Simulation of Renewable Energy Resources for Micro Grid Based Rural Electrification in Ethiopia

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Abstract: Ethiopia is a developing country where the majority of the community lives in rural areas without electricity from the grid because of unfavorable condition of the remote area. It is necessary to supply the energy needs of this rural population for better advantages; by integrates multiply stand-alone renewable energy sources. Further, the power management of these renewably energy systems is a vital. On this research we deals with modeling & simulation of photovoltaic, micro-hydro and, storage based power generation system in MATLAB/Simulink. The power generated from these combined three renewable energy sources through intelligent decision serves for selected kebele loads. This kebele (selected village) has 5.46KWhr/m^2/day amount yearly average solar radiation and 12.2411/s average flow rate. 64KW primary peak load was considered for 180 model households. The optimization result of HOMER 10KW PV, 50.4KW micro-hydro, and 18KW fuel cell optimal design is developed for electrifying the study area, for the investment cost, total present cost and unit cost of $160,780, $269,054 $0.059 respectively. Then to use the three energy resources efficiently, fuzzy logic controller based intelligent decision was used for monitoring the type and amount of resources available, as per the demand and available sources.

Keywords: Fuzzy Logic, Mat Lab, Micro-grid, Renewable Energy Resources, Load Response

1. Introduction

1.1. Background

It is important to use renewable energy sources to solve the problems of the rural population.

It is believed that developing countries, such as Ethiopia, need adequate energy supplies to solve their people's basic problems, but it is necessary to use different energy options to achieve this. Therefore, it is technically and economically difficult to fulfill the electricity demand in remote places where less density of population is there as compared to urban area. Thus, the off-grid renewable energies sources are an appropriate choice, to provide an electricity access to rural residents who are living dispersedly and far away from the main grid and lives dispersal. However, it is impossible to satisfy the energy requirement by independent energy sources because, poor efficiency, environmental condition. To overcome this, micro and mini grid based rural electrification is one of the most selected options [1, 2]. When we consider Ethiopia rural electrification rate is very slow by using grid based electrifications. Today approximately 30% of populations have access to the power grid. A 90% of electricity in the Ethiopia is consumed in urban area from this value half of it is consumed in Addis Ababa city and ¼ of it consumed in east shewa town, But Ethiopia is one of the richest renewable energy resources (Wind Solar micro hydro) country in Africa from where small portion of potential is yoked today. Therefore there are a national road map to raise electrification rate by 10-14% per year till 2037 to satisfy growth of the energy demand by extension of the national grid and stand-alone system [4, 5].

In this research, micro-grid based rural electrification using renewable energy sources which is abundant at selected village, the Solar power system and micro hydro considered as main generation sources of renewable energy to electrify the community of South west shewa. Fuel cell is us d as energy storage device due to intermittent nature of these sources. Fuzzy logic is used to deliver appropriate energy resource at required by demand. Since [3] was elaborate abundance of PV energy potential and state current and future generation composition of hydropower system in Ethiopia more attention to this alternative energy source. So the expansion of this energy division is a driving force for encouraging country's economy and the enhancement of the living standard of the rural people. This will promote to get improved health care and education, to simplify modern communication and information systems. In addition, it will diminish city migration, reduction of fossil fuel resources and deforestation as well as impurity gas release to the community. Therefore micro grid based rural electrification using renewable energy resource play a key role in this regard (referring [2]).

1.2. Literature on Micro Grid Based Electrification

The micro grid is one of the most research areas by many researchers in developed country, especially in U.S.A., E. U. and Canada [6]. It satisfies the local energy demands and operated according to its own protocols and standards [7]. However, the concepts proposed vary and there is still no common concept for micro-grids [8, 9]. The U.S. Consortium for Electric Reliability Technology Solutions (CERTS) has published a White Book [10] where a micro-grid is defined as follows:

"The Consortium for Electric Reliability Technology Solutions (CERTS) micro-grid concept assumes an aggregation of loads and micro-source operating as a single system providing both power and heat. The majority of the micro-sources must be power electronic based to provide the required flexibility to insure operation as a single aggregated system. This control flexibility allows the CERTS Micro-Grid to present itself to the bulk power system as a single controlled unit that meets local needs for reliability and security."

The most common energy sources for the micro-grid system are wind, solar, hydrogen, geothermal, biogas, micro-hydro and fossil fuels. The environmental impact of conventional sources such as coal, diesel and nuclear are given a great consideration to renewable resources. The high transmission loss and cost makes micro-grid based rural electrification most attractive option. Integrating more than one resource preferably with storage unit overcomes the issue of unreliable power production. To promote more reliable, stable, green and clean energy production, research is in progress for optimization and control tools for the Micro-grid based electrification [11, 12].

For instance, among RES, using solar PV for rural electrification is becoming popular know days ether in solar home systems or solar mini-grid systems. Among the literatures for studying the pre-feasibility of solar mini grid as compared with solar home system for electrification of rural community are shown below:

Alam et al. [13] surveyed to study preferential choice between SHS (Solar Home System) and RMG (Renewable Mini-Grid). They showed that there is a strongly inclined customer demand towards mini grid-based electricity and having the willingness to pay for electricity as compared to the solar home system. This study indicates that designing and implementing of solar PV based mini-grid for developing country get acceptance from the community.

Akiki, Georgio, et al. [14] studies pre-feasibility for the electrification of the rural off-grid village of Hurhudedanda, Nepal. To determine the most cost-effective PV configuration, three types of configurations were tested for the electrification of the entire village: Decentralized SHS, Centralized PV generation and Centralized diesel-fueled gen-set using RET screen TM software and they concluded that renewable technologies, in particular PV, can be competitive for rural electrification against conventional fuels.

Mikias Hailu Kebede [15] presented step by step calculation approach to design solar PV system for a modern average home in Shewa Robit, Ethiopia, but using step by step calculation for designing of solar PV is time-consuming and may not obtain accurate results.

Tilahun Nigussie et al [16] investigated the techno-economic and optimum configuration of a micro-hydro, Photo Voltaic (PV), and Diesel Generator-battery hybrid power system for supplying electricity to Melkey Hera village in Western Ethiopia, which is remotely located from the national grid, using HOMER software. The three years load projection was used as input by taking population growth of the community living in the village.

Halabi et al. [17] have analysed the performance of a hybrid system based on economic and environmental constraints, besides, emphasizing comparative cost analysis between different operational scenarios. HOMER software was used to model, simulate, and analyse hybrid systems and to study comparative cost analysis between different configurations including net present cost (NPC) and Level zed cost of energy (LCOE). They showed that a hybrid PV/diesel/battery system provided the best performance compared to all other scenarios and 100% RE system showed the best environmental characteristics with the highest costs.

Tu A. Nguyen et al., [18] presented performance characterization analysis in a PV-VRB micro grid system for military installations under different conditions of load and weather without considering the control strategies to maximize the efficiency of the system.

2. Research Method

The proposed hybrid system consists; a Micro hydro, solar and fuel cell as a backup, in which the energy to be produced from these renewable energy resources is controlled using fuzzy logic controller to fulfill the power demand at the required standard. Artificial intelligent based Controller is considered to use the fulfillment and quality power as per the requirement of community. The designed controller first check the amount of the load and switches ON the proper source to satisfy the load from the customer side as shown in figure 1.

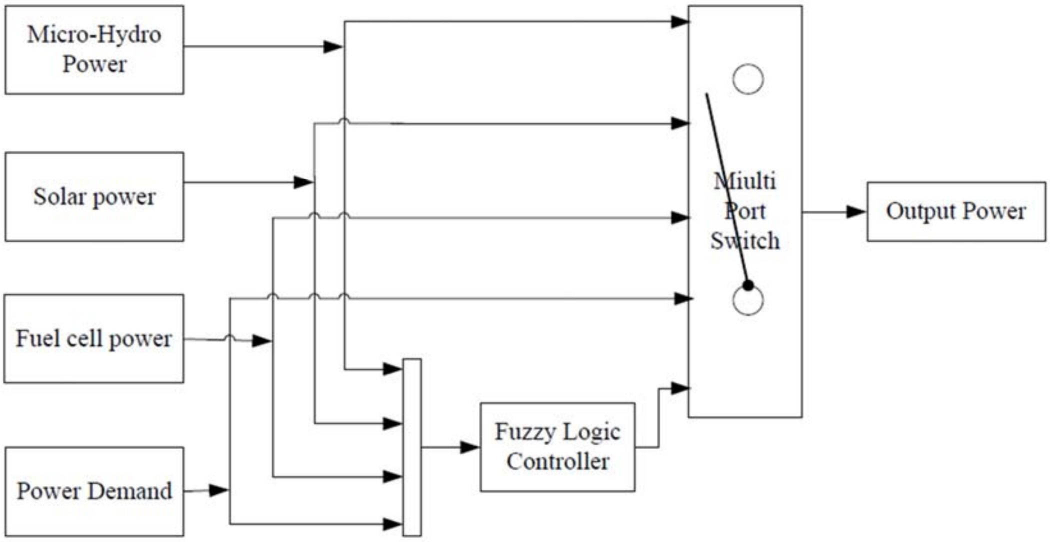

Figure 1. *Proposed Hybrid block diagram.*

In order to meet the objectives of this paper the work was performed by the following steps in order to make paper easy, manageable and systematic.

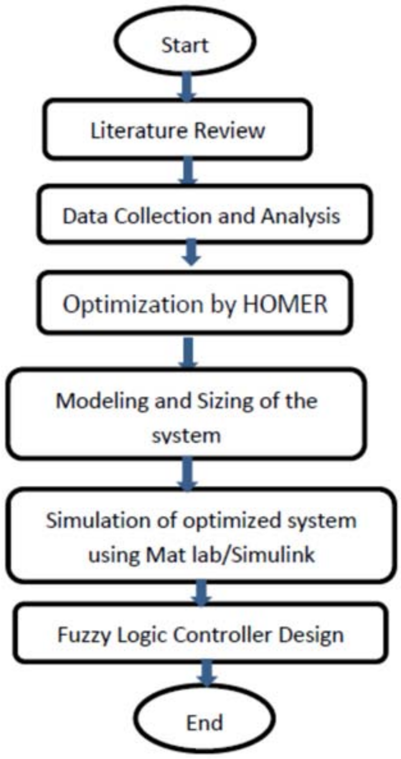

Figure 2. *General flow chart of the paper Methodology.*

To assess the micro-hydro and solar resources of the selected area relevant data collection has been taken from three basic source

a) The sunshine hours which was taken from national metrology agency of Ethiopia was converted to global solar radiation then compare with the data from NASA. Finally the minimum (4.359KWh/m^2/d) global solar radiation was used as solar panel input. The water flow rate of the selected run-off river (Aruse) data was taken from ministry of water, irrigation and energy was transferred to flow duration curve. 0.403m^3/s for design flow rate

b) Site visits and interview: Collecting the primary and deferrable electric load of the selected kebele by considering the equipment commonly might exist in rural areas of Ethiopia like television, radio, light and etc. 180 householder, 443KWh/d load was collected and forecasted to 965kWh/d for primary loads where 5.6KWh/d for deferrable load

c) Website: satellite based solar radiation data from NASA, market survey
d) Figures 3, 4 and 5 presents the model of micro-hydro, solar (PV) and fuel cell resources for selected area loads

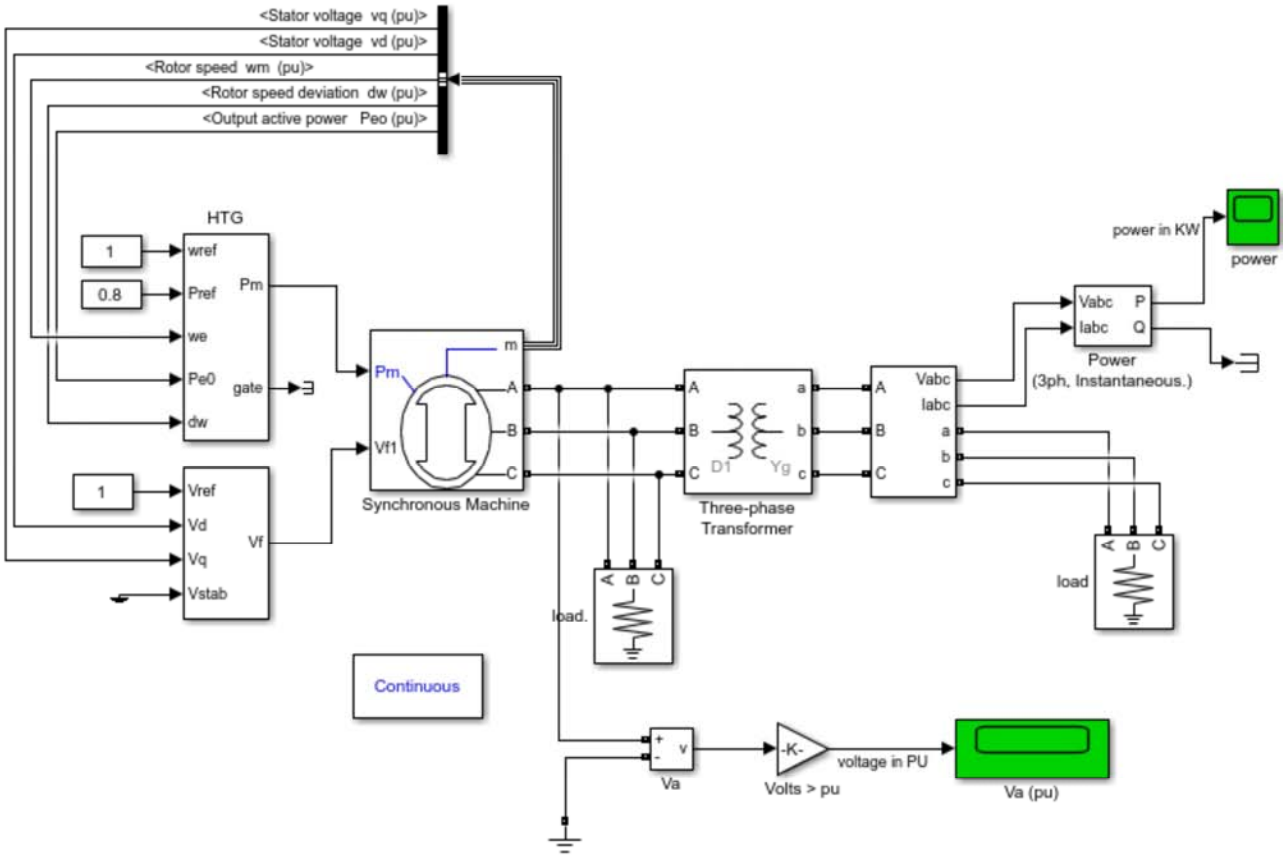

Figure 3. Simulink Model of a Micro-Hydro Power.

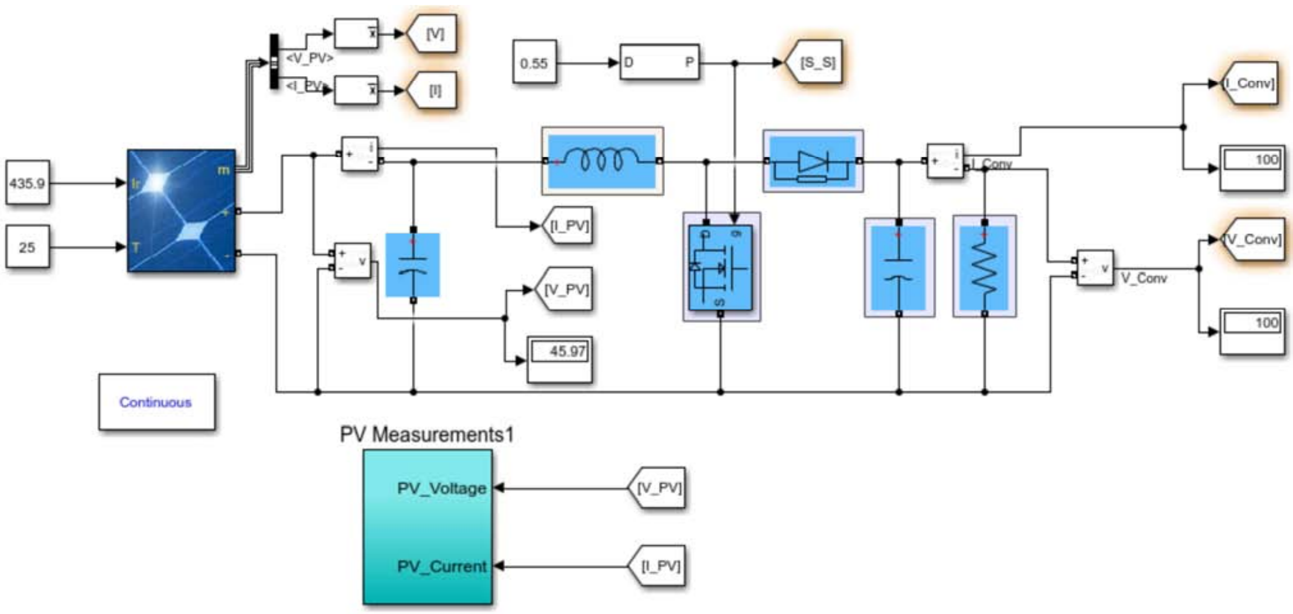

Figure 4. Simulink Model of a PV-Generator.

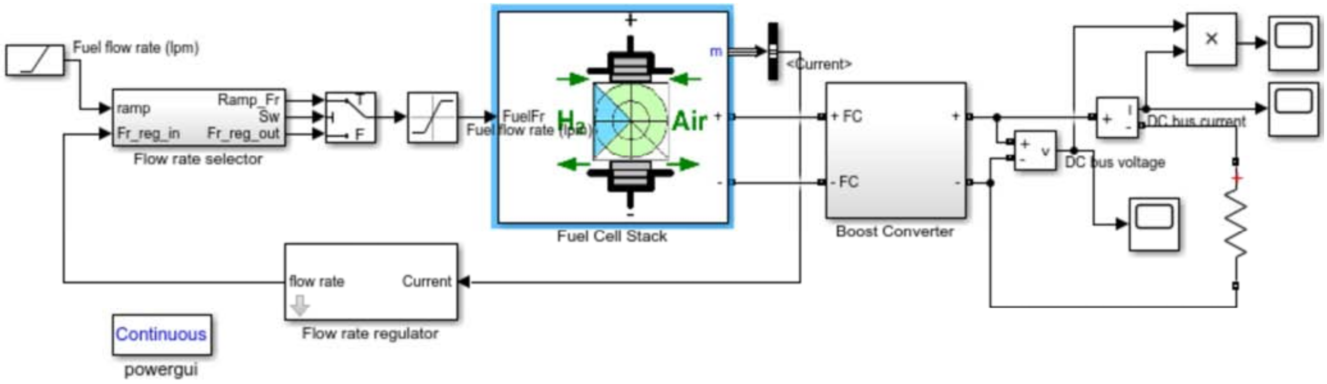

Figure 5. *Simulink Model of fuel cell.*

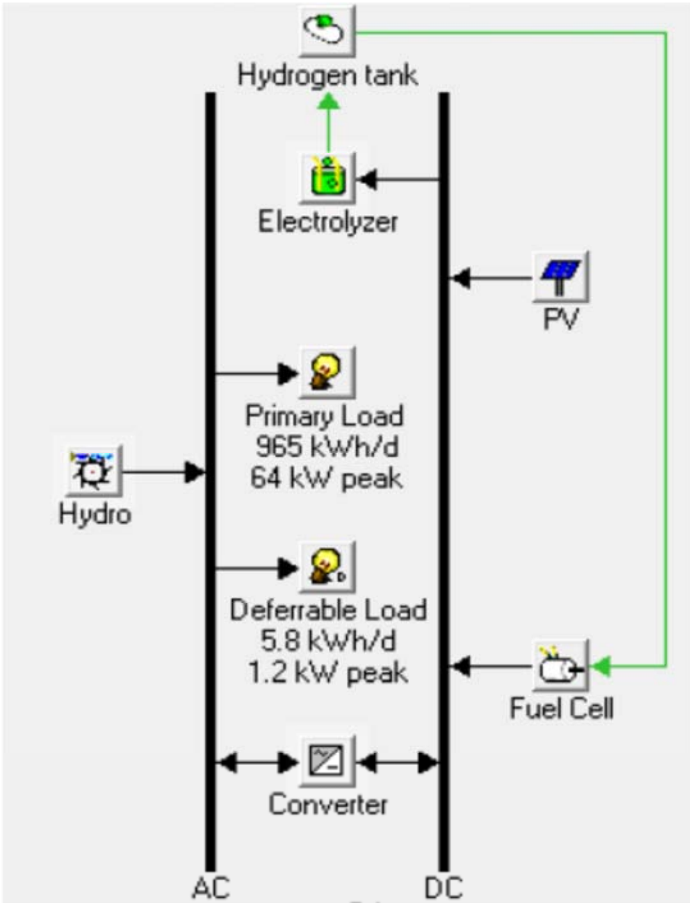

Figure 6. *Hybrid system model topology of the kebele.*

3. Simulation Results and Discussion

In this portion, it was brief discussion on the results of this research work and explains some analysis in compressive manner. The simulation result was presented in figures, graphs and tables. Let us see each of the as described below.

3.1. Hybrid System Optimization Using Homer

Figure 6 shows that Hybrid micro grid model of the overall system which describe that the loads connected to AC bus and shows the values of the load demand, Peak load and load factor respectively 965kWh/day, 64kW and a load factor of 0.633.

Figure 7 shows, the categorized optimization results (from rank 1 up to 10) that are possible configuration able to feed the system total load of model householder at selected site. The PV/hydro/fuel cell hybrid model in the seventh rank of the figure shows optimized combination as compared with PV/Micro-Hydro/Fuel cell hybrid model the one which was marked blue colour has the initial capital cost $160,780, $269,054 of NPC, operating cost is $8,470/yr, the energy cost (COE) is $0.059/kWh, input from renewable energy resources was 100%, and 0KWh/yr unmet electric load and capacity shortage therefore this setup was the best optimum

PV-hydro-Fuel Cell hybrid system configuration.

PV (kW)	Hydro (kW)	FC (kW)	Conv. (kW)	Elec. (kW)	H2 Tank (kg)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	FC (hrs)
10	50.4	18.0	14	9	5	CC	$ 159,780	8,445	$ 267,733	0.059	1.00	2,442
10	50.4	18.0	14	9	5	LF	$ 159,780	8,446	$ 267,748	0.059	1.00	2,443
11	50.4	18.0	14	9	5	CC	$ 161,780	8,333	$ 268,298	0.059	1.00	2,331
11	50.4	18.0	14	9	5	LF	$ 161,780	8,333	$ 268,298	0.059	1.00	2,331
10	50.4	18.0	15	9	5	CC	$ 160,480	8,463	$ 268,671	0.059	1.00	2,442
10	50.4	18.0	15	9	5	LF	$ 160,480	8,465	$ 268,686	0.059	1.00	2,443
10	50.4	18.0	14	10	5	CC	$ 160,780	8,470	$ 269,054	0.059	1.00	2,444
10	50.4	18.0	14	10	5	LF	$ 160,780	8,470	$ 269,054	0.059	1.00	2,444
10	50.4	18.0	14	9	6	CC	$ 161,080	8,459	$ 269,214	0.059	1.00	2,443
10	50.4	18.0	14	9	6	LF	$ 161,080	8,460	$ 269,230	0.059	1.00	2,444

Figure 7. *HOMER Categorized Optimization Result.*

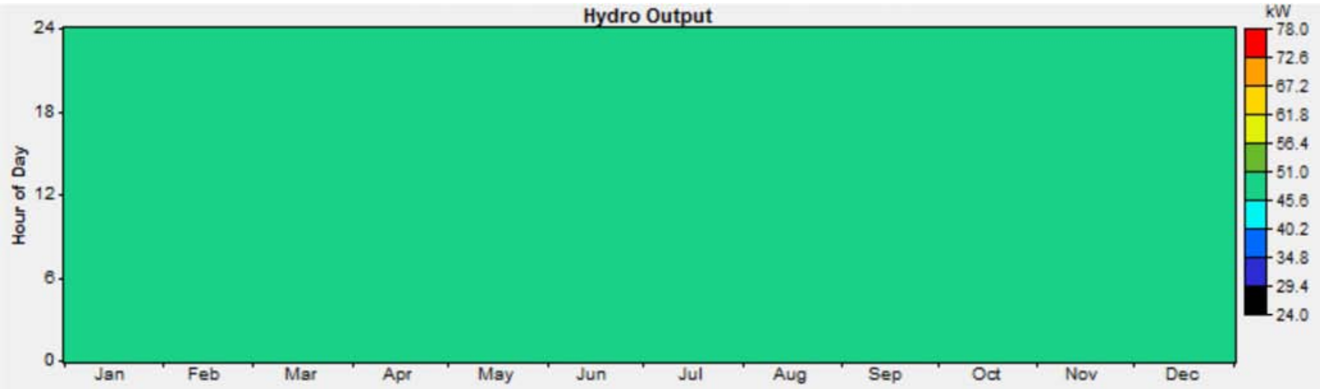

Figure 8. *Micro hydro power output system.*

The figure 8 shows the Homer result of micro hydro capacity that can generated from designed system is 50.4KW, the capacity factor 99.2%, total amount of annual electric energy production is 438,192 KWh/year and the energy (COE) to be 0.0246$/KWh.

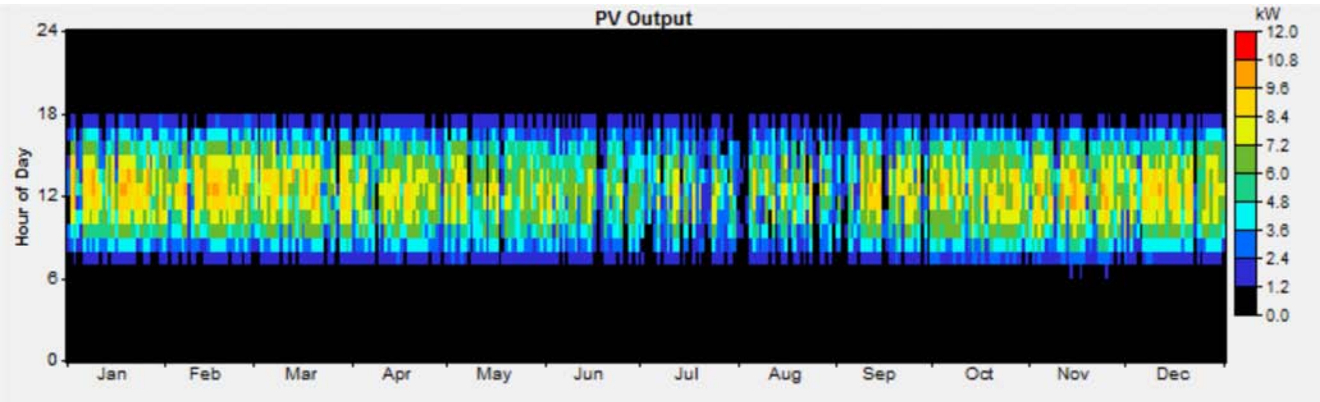

Figure 9. *Solar Power out Put.*

The figure 9 shows rated capacity of PV array was 10KW capacity factor is about 20.5%, annual energy production 17,991 KWh/y, total time of operation of operation 4,472 hour. and cost of energy 0.0989$/kWh. Consider 0.12% system efficiency the PV rated was changed from 10KW to 11.2KW. As you see above in the month of October large amount of solar ration is there. Four month (Starting from From to of September), The solar energy from the PV power production was small.

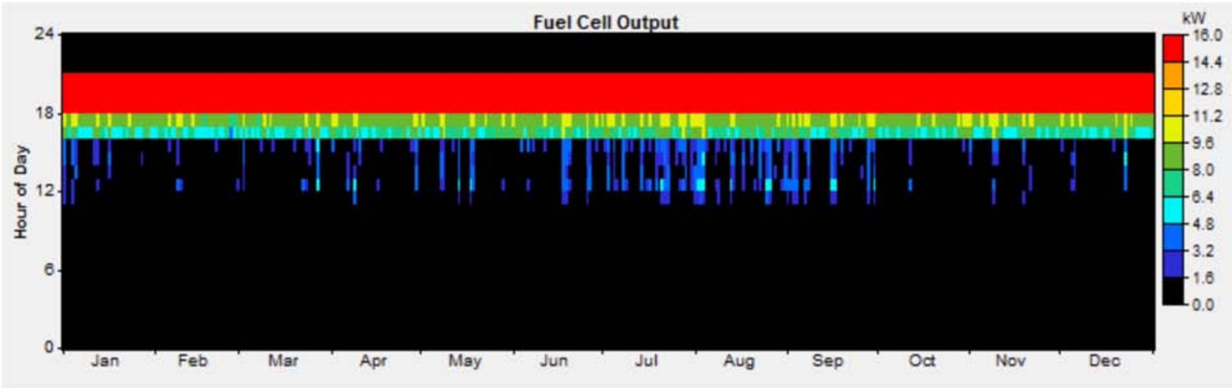

Figure 10. *Fuel cell output of the system, from HOMER.*

Figure 10 shows power output fuel cell of the system 18KW with average electrical power output of 9.76KW. Comeratively this power is large during the summer season of end of May to end of September because energy production was small during this time. Particularly, fuel cell production was in the night time 16:00-22:00.

3.2. Simulation of Overall System with Fuzzy Logic Controller

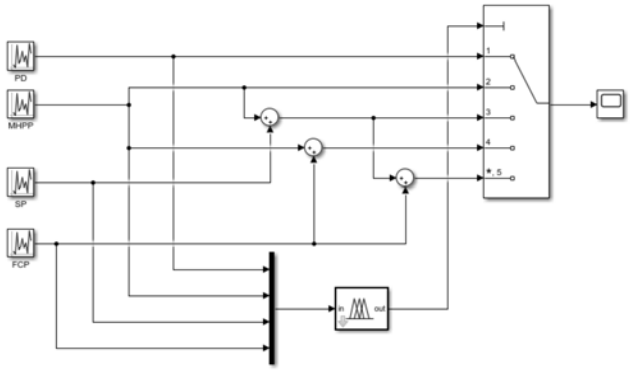

Figure 11. *Over all hybrid system in matlab/Simulink.*

The figure 11 shows solar power, Micro-hydro power, FCP power and demand power are the input parameters of the controller. PD, MHPP, SP and FCP indicates the demand power from customer side, power from Micro-hydro, power from solar system and power from FCP respectively. The power coming from each component of power sources was assumed to Gaussian random signal generator. The multiport conditional switch was taking an action according to the rules written in fuzzy logic controller.

As depicts in figure 12 the FLC has four inputs and one output. The input linguistic variables of FLC are Micro hydro power (MHPP), solar power (SP), and Fuel cell power (FCP) and Power demand (PD) where as the single Output linguistic variable was out power (PO). Each input linguistic variable has three linguistic values called LOW, MEDIUM and HIGH and the output linguistic variable has MHPP only, MHPP+SP, MHPP+FCP, MHPP+SP+FCP linguistic values. The linguistic values like LOW, MEDIUM and HIGH are subject to design

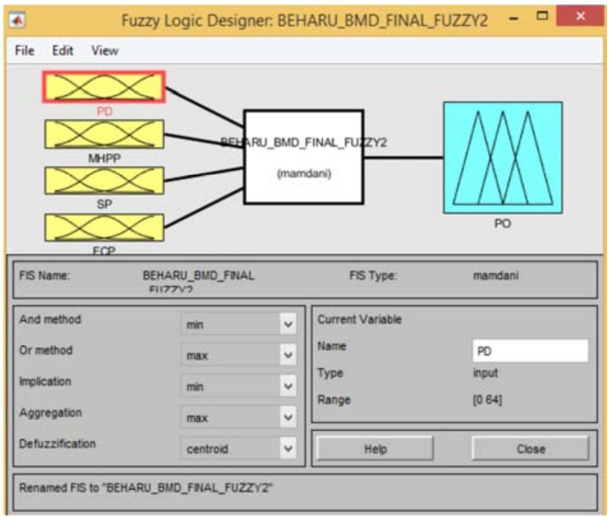

Figure 12. *Fuzzy Inference Model.*

One scenario was taken to evaluate the designed Fuzzy Logic Controller at different operation condition of solar, micro hydro and fuel cell regarding of power demand and other condition for space limitation.

Scenario one: -If for example the demand power PD is 30KW, MHP is 11KW, SP is 8KW and FC is 0KW, and then the output power of Fuzzy Logic Controller is indicated as in figure 13

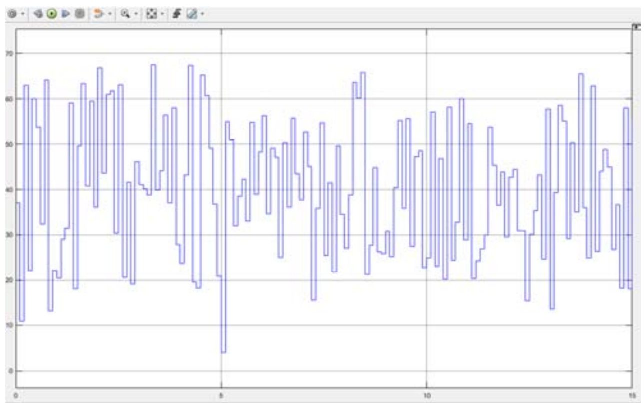

Figure 13. *Simulation result of Fuzzy Logic ontroller for scenario one.*

In case scenario one the demand power is 30KW. The p.u value of this value was 0.46875. The out power from the controller in the scope indicates around 37.33KW. This was to say for the demand (30KW), the appropriate output power from the controller was 37.33KW (0.5832813p.u) which was correct. That means; the power demand found in low linguistic value and their appropriate resources were MHPP+SP.

4. Conclusion

In this paper, Design and simulation of micro-grid based isolated PV and micro-hydro intelligent combined system were proposed and analyzed using HOMER and MATLAB/Simulink software. This was done first to assess solar and micro-hydro potentials of selected village. The solar and micro-hydro resources data profile was evaluated using HOMER software. Then, based on these potentials, a feasibility study for a stand-alone hybrid setup electric power supply for the community (i.e. 180 householders) was done after a simple load forecasting of the load within live span of 12 years, site visiting and collection of data's which was estimated to have a primary peak demand of 64KW.

The result optioned from the HOMER software gave many alternatives of possible combined systems with different level of renewable energy resource penetration in which the optimum excellent sorted based on some important parameters such as less unmet load less capacity shortage and NPC. Therefore, PV/Micro-hydro and fuel cell of row number 7 hybrid renewable power system was the best among the many possible and feasible systems.

From simulation result, the initial capital cost $160,780, $269,054 of NPC, operating cost was $8,470/yr, the cost of energy (COE) is $0.059/kWh, contribution from renewable resources is 100%, and 0KWh/yr unmet electric load and capacity shortage have been found. Also, in this simulation the majority of energy optioned from micro-hydro, which accounts 91%, the PV about 4% and 5% was to be produced from the backup fuel cell.

In general, this work relates the technical, economic and environmental effect of the stand-alone systems. To use the produced power using the above mentioned three energy resources wisely, fuzzy logic controller was used to make an intelligent decision by sensing the type and amount of resources available, then it selects the appropriate alternative source, and to perform this Fuzzy rule have been written in fuzzy rule editor and each components of the proposed hybrid system has been modeled using Matlab/Simulink. Someone who will interest in this energy efficient utilization technologies for any remote area site, apply other type of intelligent energy control system.

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