An Innovative Method to Hybrid Renewable Energy Controlling Strategy Using Artificial Techniques

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***Abstract*— This study exhibits an optimal scheme for designing and analyzing a hybrid renewable energy management system (HREMS) with the help of artificial control techniques over conventional techniques. The system is an integration of photovoltaic array, AC wind generator, biogas generator, battery and converter. Size optimization of the system components has been done using Homer. For the utilization of renewable sources and minimization of the power loss, an energy management system has been designed and optimized through Fuzzy logic controller (FLC). FLC monitors the load demand and generates control signal for switching depending on knowledge based fuzzy rules and ensures the effective supply of energy to the load. To extract the maximum power from the photovoltaic array and to improve the system response a genetic algorithm tuned PID controller based maximum power point tracker (MPPT) is designed and employed to deliver maximum power at varying weather conditions. Simulation result of control technique has been compared with other conventional system like adaptive neuro fuzzy interference systems. Proposed method shows the improved efficiency in MPPT system, flexibility in use, cost effectiveness of management system and lower carbon emission.**

***Index Terms*— Fuzzy Logic Controller (FLC), PID controller, Genetic Algorithm (GA), photovoltaic arrays, Maximum Power Point Tracker (MPPT), wind turbine, biogas generator**

I. Introduction

Electricity usage is extending well ordered around the world. Social and economical development of any country is close by incomprehensible without energy. The most dominant power resource in Bangladesh is natural gas. Natural gas serves about 66% of the demand and the other sources are oil, hydropower and coal [1]. Non-renewable energy sources are limited assets which cause air, water and soil contamination, and deliver ozone harming substances with the expanded measure of carbon dioxide emanations that adds to an Earth-wide temperature boost. In Bangladesh, 93% of the population has access to electricity with a per capita availability of 136kWh per annum [2]. On the next decade our demand will reach to 30000MW [2]. Again, improper energy management system is a great problem in Bangladesh. Due to which a percent of total energy is being lost. As the gas reserve are going to be finished within 10 years, finding the new scope for negotiating upcoming crisis of energy is the demand of time. One of the best solutions to this unwanted crisis is to deal with renewable energy and utilize the natural resources of clean energy which can help us protecting our environment [3]. Proper steps should be taken in order to handling the probable energy scarcity. Sun energy, wind energy and biomass energy are three of the most encouraging inexhaustible power age advances among accessible feasible sources. So we need proper control strategy to ensure effective supply of energy. Different kind of energy control strategies have been used over the years. Adaptive neuro fuzzy interference system (ANFIS) is one of the most commonly used systems which can deal with varying weather conditions and load conditions. Despite wide acceptance rate among researchers, it has some drawbacks. ANFIS experiences constraints that end applications in issues with huge information sources, for example, revile of dimensionality and computational cost [4]. Another control strategy is fuzzy logic controller which can be framed with nature inspired algorithms like genetic algorithm [5]. It incorporates adaptability, instinctive information based structure, simple calculation, vulnerability, and nonlinearity [6].

In this paper we have proposed an ideal model of cross breed inexhaustible framework. Generation of energy from sustainable sources is the best decision for securing nature [7]. It is an answer towards the

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constrained accessibility of non-renewable energy source, environmental change. Once more, there are numerous sorts of sustainable power sources accessible in Bangladesh, for example, wind energy, sun powered energy, hydro energy, biomass energy etc [7]. Sun powered energy is accessible in everywhere in Bangladesh. In any case, wind energy is feasible for some coastal zone in Bangladesh [8]. We have chosen Patenga for generating the power since this shoreline is progressively reasonable for wind and sun energy at once with incorporated hybrid system. Besides, this is a prospective area for utilizing organic biomass energy as there is healthy availability of the biomass in nearest region. Since this is a characteristic shoreline, legitimate usage of inexhaustible sources is most critical to shield the earth from peril of non-renewable energy source. This study is proposed for 26 small shops in Patenga Beach and there is 156 kW load demand per day. The accessible normal wind speed is 2.380 meter per second in Patenga where 2.5 kW wind turbine is reasonable.

Considering the above situations and obstacles, a hybrid renewable energy management system is designed and analyzed using fuzzy logic controller. Size optimization of renewable sources has been done by Homer optimization model which is required for fuzzy based energy management system. Again, getting the maximum power from solar panel is literally impossible without any tracking system. In order to obtaining the paramount performance and power from the photovoltaic panel, genetic algorithm and PID based artificial intelligent technique has been used. Application of artificial intelligent techniques like Fuzzy control techniques, genetic algorithm in the field of hybrid energy systems can bring revolutionary change in terms of flexibility, reduction of power loss and cost effectiveness.

II. Methodology

A. Study Area & Resources Assessment

Patenga is an ocean shoreline which is 14 kilometers away from Chittagong city, Bangladesh. Its location is 22 degrees 14.73 minutes North latitude and 91 degrees 47.24 minutes East longitude [9]. The area is facilitated with great aspect of solar, wind and healthy availability of municipal waste in nearest region. The main motto of this paper is the utilization of all available renewable resources to generate electricity for a small market containing 26 shops near Patenga. Size optimization methodology is shown in Fig. 1. From the outset, we have chosen Patenga as our investigation zone. At that point, solar radiation, wind speed and biomass asset information have been aggregated. From that point onward, a load profile and specified the technical parameters have been structured. Finally, ideal outcome by simulation of input information utilizing HOMER optimization tool is obtained.

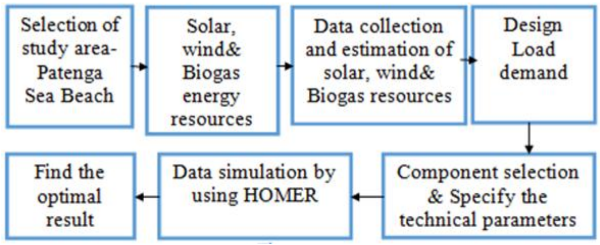


Figure 1. Size optimization methodology.

For this exploration, month to month solar radiation and wind speed information have been gathered from NASA and Chittagong weather office for one year have been shown in Table I. Average municipal waste data has been collected from Chittagong City Corporation (CCC).

TABLE I. Monthly Radiation, Speed of Wind and Biowaste Data of Patenga, Chittagong, Bangladesh [10-12]

Month	Daily Radiation (kWh/m^2/day)	Daily Radiation Weather office Data (KWh/m2/day)	Monthly average wind speed(m/s) Height(20m)	Wind Speed(m/s) Weather office Data (KWh/m2/day)	Available Bio Waste (tones/day)	Average Municipal waste from CCC (tones/day)
January	4.211	4.240	2.480	2.220	1.500	1200
February	6.322	6.350	2.730	2.220	1.500	1200
March	7.781	7.780	2.900	2.500	1.500	1200
April	8.107	8.107	3.070	2.500	1.500	1200
May	7.757	7.757	3.040	3.050	1.200	1.200
June	5.047	5.040	3.420	2.780	1.300	1200
July	5.596	5.590	3.250	3.050	1.400	1200
August	4.320	4.320	2.930	2.780	1.500	1200
September	4.665	4.670	2.440	2.500	1.600	1200
October	4.161	4.180	2.040	1.390	1.400	1200
November	6.865	6.910	2.240	1.940	1.500	1200
December	5.211	5.250	2.330	1.670	1.200	1200
Average	5.742	5.850	2.739	2.380	1.5	1200

B. System Description

Fig. 2 demonstrates a square outline for proposed framework which comprises of photovoltaic arrays, biogas generator, wind turbine generators, converter and batteries. In order to satisfy the load request, photovoltaic arrays, wind generators and biogas generator supply the power. The abundance vitality from sustainable sources is put away in the battery relying upon condition of charge.

The battery is utilized as reinforcement, for the situation when the provisions from inexhaustible sources are inaccessible. The converter is utilized both as rectifier and inverter. Genetic algorithm-PID based MPPT extracts maximum power from photovoltaic array and fuzzy logic controller generates the control signal to ensure effective flow of energy using knowledge based rules.

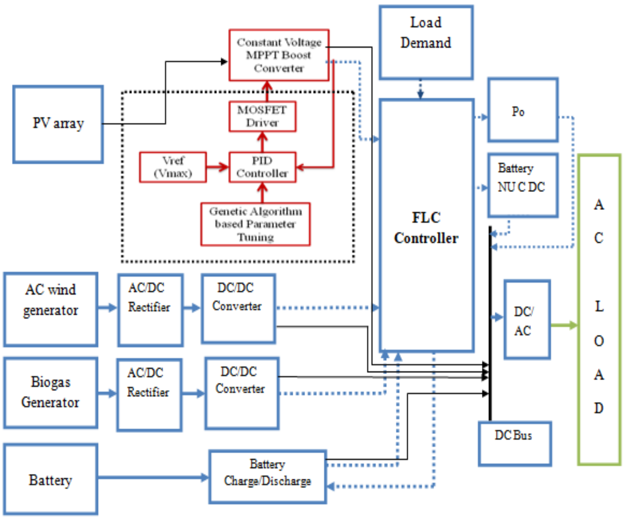


Figure 2. Proposed system block diagram.

C. *Model of Photovoltaic Array*

Photovoltaic impact is the basis for converting energy adapted from the sun to electrical energy [13]. The semiconductor materials of photovoltaic arrays are responsible for the conversion of light into electricity. Following equation is the expression of power supply from photovoltaic arrays [14].

$$P(t) = \eta.A.S(t) \tag{1}$$

Notably, η =Productivity of photovoltaic array,

A = complete territory of photovoltaic arrays in meter square

S (t) = Solar radiation in kilowatt per meter square

Fig. 3 demonstrates the average monthly solar radiation of Patenga shoreline.

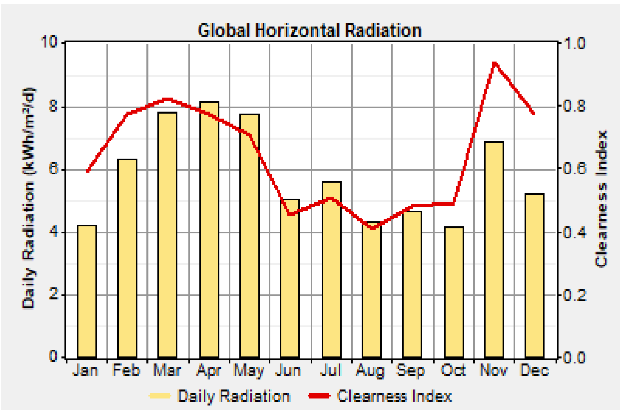


Figure 3. Average monthly solar radiation data.

5kW solar system has been used as per simulation result. The substitution expenses and capital cost are $600 and $700 individually [15]. 15 years of lifetime has been considered for the system and there is no tracking system involved.

D. *Model of Wind Turbine*

Wind turbine compels mechanical energy acquired from the speed of wind into electricity. Due to change in temperature and pressure of the moving air of earth surface atmospheric change is made which is termed as wind [16]. Wind speed directly related to the power output of wind turbine. When wind speed increases, the output power increases proportionally and vice-versa. Conversion of wind energy is limited to 59 percent owing to limit of Betz. Following equation is the expression of the generated power from the wind turbine [16]:

$$P = 0.5kC_p\rho AV \tag{2}$$

Where, k = 0.00013 (power yielding constant)

A = Region opposite to the bearing of stream in m^2

V = Velocity of wind in m/s

Cp = Coefficient of maximum power ranges from 0.25 to 0.45.Theoretical maximum is 0.59

ρ =surrounding air density in kg/m^3

P = Generated power from wind turbine in Watts.

Hourly average wind speed data of different months is shown in Fig. 4.WES 5 Tulipo model has been selected by taking environmental conditions and wind speed of the selected area into consideration. Table II demonstrates the technical specification of Wind Energy Solution (WES 5) Tulipo turbine.

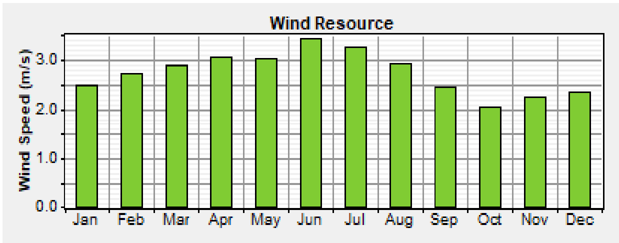


Figure 4. Average monthly wind speed in Patenga.

TABLE II. SPECIFICATION OF WIND TURBINE IN GENERAL [17]

Stipulations	Particulars
Manufacturer	Wind Energy Solutions
Life span	At least 15 years
Power production	2.5 kW(at 140 rpm)
Speed(cut in)	3 mete per second
Speed(cut out)	20 meter per second
Wind speed(rated)	9 meter per second
Quantity of turbine blades	3
Dia.(Rotor)	5 meter
Noise Dimension	35 dB at rated speed(at 20m)
Output Voltage	220V,50Hz Single phase

Considered capital expense for every turbine is $500. Again, substitution and upkeep expenses are $400 and $10 per year which are shown in Table IV. The simulation program finds an ideal arrangement of 4 turbines and life span of considered turbine is expected to be at least 15 years.

E. General Model of Biogas Generator

Biogas, a kind of biofuel, is typically made from the deterioration of regular waste. Exactly when characteristic issue, for instance, sustenance scraps and animal waste, separate in an anaerobic circumstance they release a blend of gases, basically methane and carbon dioxide. As this rot happens in an anaerobic area, the route toward conveying biogas is generally called anaerobic ingestion [18]. In this system 15 kW biogas generator is used which can effectively convert the bio energy in electrical energy. Detail information and specification of Biogas generator are shown in Fig. 5 which depends on Table III.

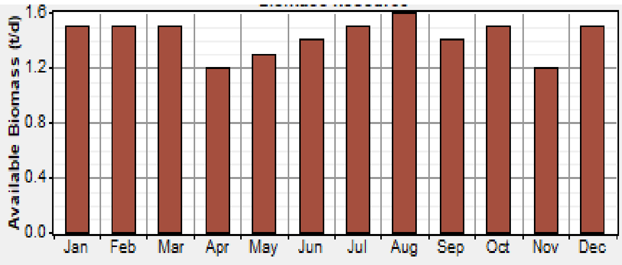


Figure 5. Average monthly Biomass fuel.

TABLE III: SPECIFICATION OF SELECTED BIOGAS GENERATOR [19]

Specifications	Details
Producer	Weifang Naipute Gas Genset Co. Ltd.
Model	15GFT
Rated power	15 kW
Frequency	50 Hz
Speed	1500 rpm
Rated Voltage	230/400 V
Starting Mode	Electrical
Rated Current	27 A
Cylinder Number	4
Exciting Method	AVR brushless

F. General Model of Battery

The flow of energy is continued by the discharge of battery which saves overabundance energy. Existence time of battery relies upon charge or release time every day. Battery life span is subjected to be 5 years and S6CS25P model battery is been used in proposed framework [20]. The substitution and capital costs of battery are $900 and $1000 respectively which is appeared in Table IV.

G. Converter Model

The capacity of converter, utilized as rectifier and inverter, is 7kW which adds capital cost of $150 and substitution cost of $130, appeared in Table IV [21].

TABLE IV. COMPONENTS AS INPUT TO THE HYBRID SYSTEM

Quantity	***Size (kW)***	***Capital ($) for 1 kW***	***Replace ment ($) for 1 kW***	***O & M ($) per year***	***Life Time***
Photovoltaic arrays	5	700	600	10	15 years
Biogas generator	15	800	700	110	20000 hour
Wind Generator	6*2.5	500	400	10	131400 hour
Battery	6.94 kWh	1000	900	8	5 years
Converter	7	150	130	5	15 years

H. Load Profiles of the Study Area

The load demand of proposed shops in the study area is 156 kWh per day which is appeared in Fig. 6 and Fig 7. Load profile is divided into two different periods of the year i.e. March to November and December to February. Assumed load variation is 15%.

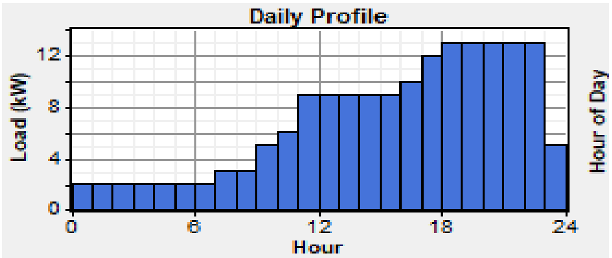


Figure 6. March-November 24 hours load profile.

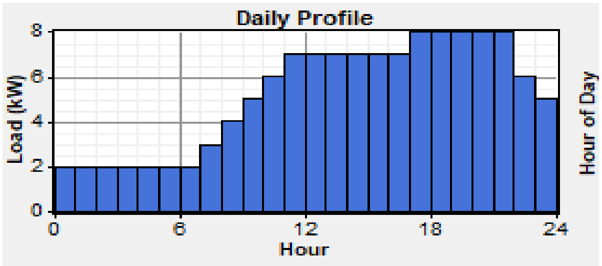


Figure 7. December- February 24 hours load profile.

Two types of electrical appliances i.e. compact fluorescent lamp and fan during site visit. 26 shops have been considered under this energy management system and electrical load detail of the shops has been demonstrated in Table V.

TABLE V. APPLIANCES OF SHOPS

Description	Quantity of Appliances	Power in watt	Total watt Ratting(W)	Hour	Watt hours /day
Compact Fluorescent Lamp	10	24	240	10	2400
Fan	5	60	300	12	3600
Total(1 Shop)					6 kWh/day
Total (26 Shops)					156 h/day

III. Homer Optimization Model

A compositional arrangement has been created with the load demand, available resources and input components of the system. Adapted optimization process generates the detail output which includes the net present cost, fraction of energy etc. In this framework, the major sustainable power sources are biogas, solar and wind energy. Here, photovoltaic array produces direct current which is converted to alternating current before feeding to the load. Again, wind turbine and biogas generator produces alternating current which is converted to the direct current when energy is stored in the battery. In that point, converter can act as rectifier and inverter according to the system requirement. Homer modelled hybrid renewable energy system is shown in Fig. 8.

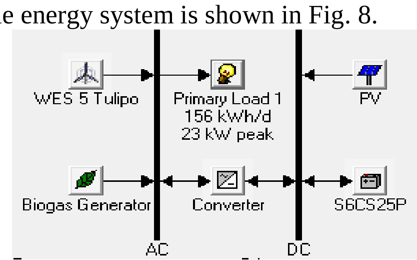


Figure 8. HOMER modeled hybrid renewable energy system.

IV. Photovoltaic MPPT System

Tracking system for photovoltaic panel is needed for getting the maximum power. Different kind of explanations related to MPPT controller has been discussed over the years. Among different methods, stable voltage method has been selected due to its flexibility of use [22].

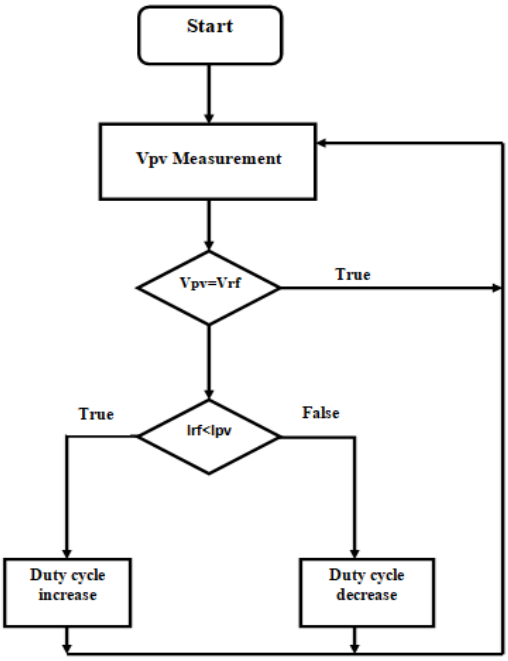


Figure 9. Stable voltage method- flow chart [23].

In this research, for HREMS, one MPPT technique has been utilized for maximization of power from photovoltaic panel using GA and PID based Controller. It is the most straightforward MPPT controller, and has a fast response. The steady voltage strategy does not require additional data acquisition tools with the exception of the estimation of the photovoltaic voltage. It requires a PID controller to regulate the duty cycle of the converter so as to keep up the photovoltaic voltage close to the most extreme power point [24]. The controller consistently directs the voltage of photovoltaic system and keeps it up near its maximum power point (MPP) by coordinating the photovoltaic module output voltage to a steady reference voltage (Vref). The reference voltage is being set as per the maximum output voltage calculated in standard testing condition. Fig.9 shows the flow chart of stable voltage method.

A. System Block Diagram

Unstable climate condition is the prime obstacle which is negotiated by the MPPT system. Here, the MPP voltage (Vmax) is taken as a reference to the PID controller and summed with the feedback from converter output. Again, PID controller parameters (P,I,D) are tuned by genetic algorithm. After comparing the reference voltage and current output voltage from converter, controller generates duty ratio through PWM for boost circuit. Generated duty cycle triggers the gate of the MOSFET switch which is incessantly attuned to follow the most extreme power point. Overview of genetic algorithm-PID based MPPT is shown in Fig. 10.

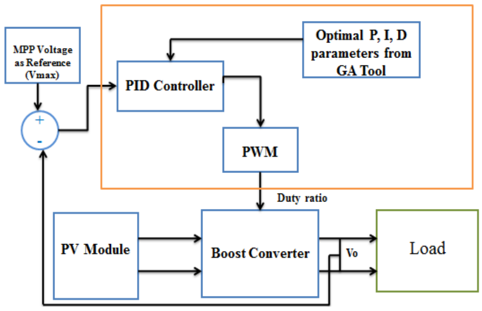


Figure 10. Overview of GA-PID based MPPT.

B. Design of GA-PID Based Controller for MPPT

PID controller is an amalgamation of three types of control act such as- proportional (P), Integral (I) and Derivative (D) [25]. Time domain behaviour in different kind of dynamic plants is done by this controller. Here, U(t) is the reference signal and e(t) is the error signal which is shown in Fig. 11. e(t) is summed up with the u(t) to evaluate the output of the plant.

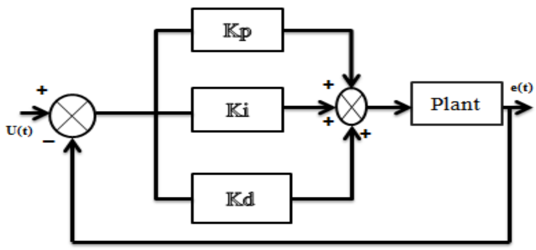


Figure 11. PID Controller [25].

$$U(t)=K_p e(t)+K_i \int e(t)dt+ K_d\, de(t)/dt \qquad (3)$$

Static MPPT tracking efficiency is given by,

$$\eta_{static} = \frac{P_o}{P_{max}} \times 100 \qquad (4)$$

Po= Output power of photovoltaic module under steady state, *Pmax* = Maximum power of the photovoltaic module under certain condition.

For designing the PID controller for photovoltaic MPPT transfer function of boost converter is being used as a plant. Genetic algorithm is employed to optimize the Proportional (P), Integral (I) & Differentiate (D) gain which improves the closed loop system response . Firstly, we obtain transfer function model of subjected boost converter by calculating all the parameters. After that, two different objective programs have been written to run the genetic algorithm tool. Response of the system is demonstrated in result and analysis section. Circuit diagram of boost converter and transfer function model for MPPT are shown in Fig.12 & 13.

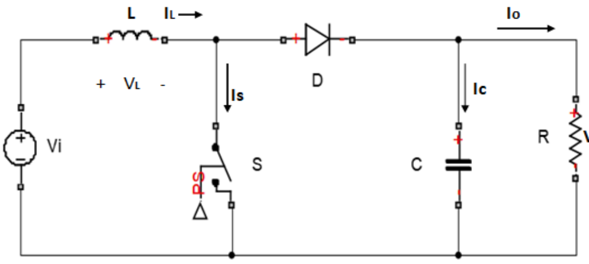


Figure 12. Circuit diagram of Boost Converter [25].

Applying Kirchhoff voltage law to the circuit when switch is off [26],

$$-Vi(s)+LsI(s)+(R \parallel \frac{1}{Cs})I(s)=0 \qquad (5)$$

$$\Rightarrow Vi(s)=I(s)Ls+\frac{R.\frac{1}{Cs}}{R+\frac{1}{Cs}}I(s) \qquad (6)$$

$$\Rightarrow Vi(s)=I(s)Ls+\frac{R}{RCs+1}I(s) \qquad (7)$$

$$\Rightarrow Vi(s)=\frac{RCLs^2+Ls+R}{RCs+1}I(s) \qquad (8)$$

$$Vo(s)=(R \parallel \frac{1}{Cs})I(s)=\frac{R}{RCs+1} \qquad (9)$$

$$\frac{V_o(s)}{V_i(s)}=\frac{\frac{R}{RCs+1}I(s)}{\frac{RCLs^2+Ls+R}{RCs+1}I(s)} \qquad (10)$$

$$T(s)=\frac{V_o(s)}{V_i(s)}=\frac{R}{RCLs^2+Ls+R} \qquad (11)$$

Converter parameters (R, L, C) calculation considering

Vref= 24V, Power =75V, Vi(min)=7 V and fs=70kHz.

$$D=1-\frac{Vi(\min)}{Vo}=1-\frac{7}{24}=0.71=71\% \qquad (12)$$

$$di = Iripple \times \frac{P}{Vo} \times \frac{Vo}{Vi(\min)}$$
$$=0.2 \times 3.33 \times 3.42 \approx 2.2A \qquad (13)$$

$$L=\frac{2.69Vi \times (Vo-Vi)}{di \times fs \times Vo}$$
$$=\frac{18.83 \times 17}{2.2 \times 70000 \times 24}=8.69 \times 10^{-5}H \qquad (14)$$

$$dv = Vo \times \frac{dv\%}{100}=24 \times \frac{1\%}{100}=0.24V \qquad (15)$$

$$C=\frac{Io \times D}{dv \times fs}=\frac{3.3 \times 0.71}{0.24 \times 70000}=1.4 \times 10^{-4}F \qquad (16)$$

$$Ro=\frac{Vo}{Io}=\frac{24}{3.3}=7.2\Omega \qquad (17)$$

$$Vo(s)=(R \parallel \frac{1}{Cs})I(s)=\frac{R}{RCs+1} \qquad (18)$$

$$\frac{V_o(s)}{V_i(s)}=\frac{\frac{R}{RCs+1}I(s)}{\frac{RCLs^2+Ls+R}{RCs+1}I(s)} \qquad (19)$$

$$T(s)=\frac{V_o(s)}{V_i(s)}=\frac{R}{RCLs^2+Ls+R} \qquad (20)$$

Obtained Transfer Function and Model:

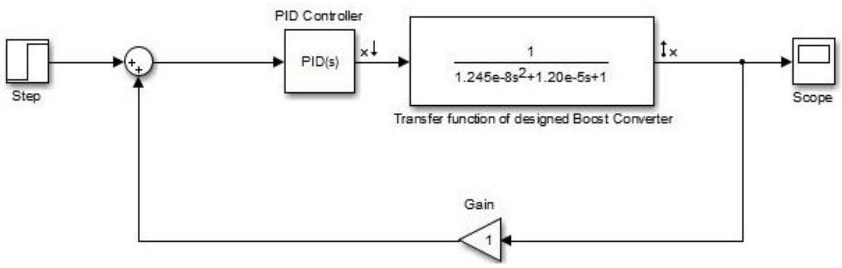


Figure 13. Transfer function model for MPPT.

C. *Flow Chart of MPPT System*

Maximum power point voltage that is obtained from solar panel is being checked and given as the reference or set value which is at most 24V in system. After PID parameters are optimized by the genetic algorithm, converter has become ready for starting conversion. In the first condition the system will check whether the input voltage (current output voltage of MPPT) is less than equal 24 V or not. If the condition is true (yes) than the system will go into the boost mode. In boost mode the output voltage of the system will be checked again for a new condition which will verify whether the output voltage is equal to set value (24V) or not. If the condition is true (yes) then duty will not be increased and current duty ratio will be maintained as our target is achieved. Again, if the condition is not true than the duty ratio will be updated until the set value of the controller is obtained. The loop will be maintained and started again the conversion if any fluctuations in the output voltage happen due to varying weather conditions. On the other hand, if the first condition is not true the system will not update any duty and duty will be set to zero, the converter will not work in buck mode, as over voltage can hamper the system. Overall, maximum power point tracking system will maintain the maximal power point voltage and ensure the generation of maximum power with improved system response. Fig.14 shows the flow chart of the proposed MPPT system.

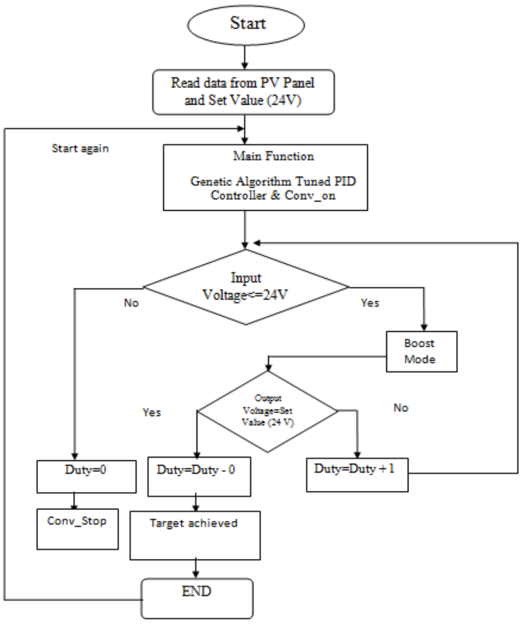


Figure 14. Flow chart of the MPPT system.

D. *Physical Diagram of PID Controller Based Photovoltaic MPPT*

There are two main parts of the system which are controller part and boost circuit. Parameters of the boost circuit have been calculated as per described in sub-section B. And PID controller is optimized as per sub-section C. The inputs to the controller are reference voltage which is targeted to obtain and the output voltage signal from the voltage measurement across the boost circuit load resistance which is used as feedback to the controller. The difference between two inputs goes into the PID controller and PID controller generates duty ratio through pulse with modulation to the MOSFET switch in the boost circuit and adjust the duty until the output voltage is equal or near to the reference point. As output voltage is maintained equal or near to maximum power point voltage, the delivered power from the solar panel becomes maximum. Proposed PID controller based photovoltaic MPPT has been designed using MATLAB Simulink which is appeared in Fig.15.

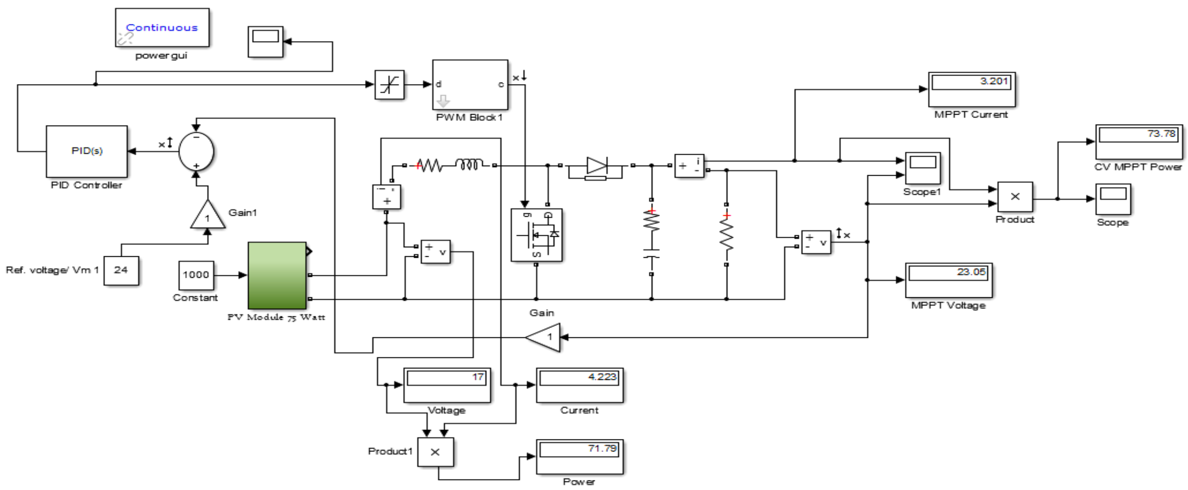


Figure 15. Physical diagram of PID controller based photovoltaic MPPT.

V. FLC Based HREMS Design

Fuzzy logic control is a branch of artificial intelligence techniques which can deal with the thoughts which are not completely true or completely false. There are four steps to approach for designing a fuzzy logic controller for hybrid system [27]. Firstly, the real scalar values of inputs are converted into fuzzy set. Secondly, a number of fuzzy rules are made depending on the human intelligence. Thirdly, fuzzy inference is done by comparing the inputs and fuzzy rules. Finally, fuzzy set is defuzzified to give the real values as output.

Proposed HREMS is designed with FLC to ameliorate the efficiency and reduce the system intricacy. It deals with five inputs along with two outputs which are appeared in Fig. 16. We have used triangular type membership function (MF) for the inputs which are PHOTOVOLTAIC module, wind generator, biogas generator, and load demand (LD) and state of charge (SOC). Determining the range of membership functions of inputs and outputs is the most significant phase to design the FLC for HREMS. Size optimization using homer optimization model was done previously. Hence, sensitive results were generated based on daily load profile and cost analysis. Optimization results have been considered for scaling the range which is divided in different parts- low MF, medium MF and high MF. Input MFs are demonstrated in Fig.17,18,19,20,21. Output membership functions are Po and NU-C-DC (Battery). Po is denoted as a combination of wind (S1), PV+wind (S3), Wind +biogas (S5) and PV+Wind+Biogas (S6). Battery mf has three types of switching options which are denoted as not in use (S1), charging (S2) and discharging (S3).

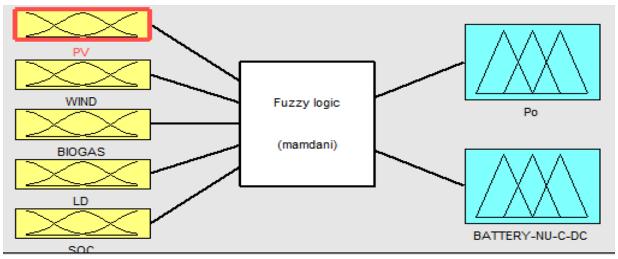


Figure 16. Block diagram of proposed fuzzy logic controller.

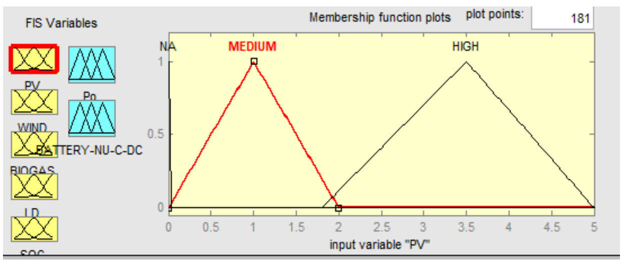


Figure 17. Photovoltaic-membership function.

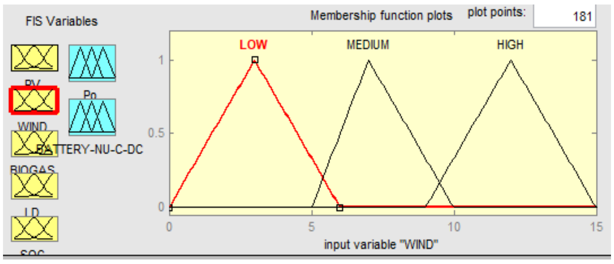


Figure 18. Wind generator-membership function.

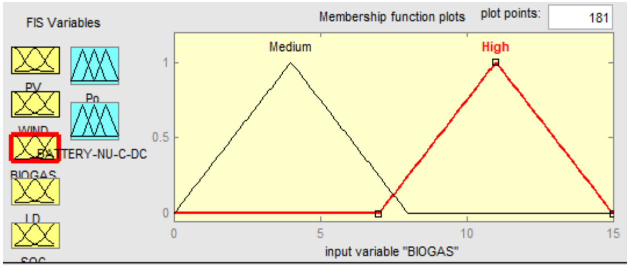


Figure 19. Biogas generator-membership function.

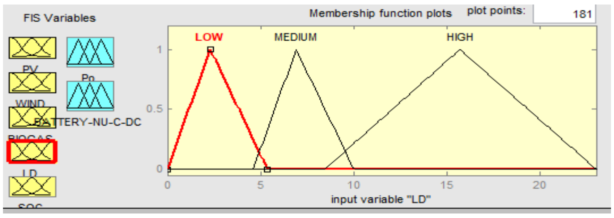


Figure 20. Load demand-membership function.

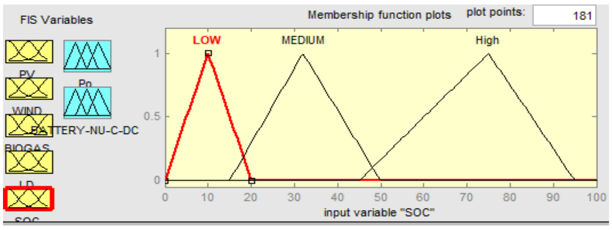


Figure 21. Battery SOC-membership function.

Intelligent rules (IF-THEN) in FLC are used to relate between inputs and outputs of the HREMS. Based on diverse operational scenarios, 130 fuzzy rules have been constructed for the development of effective management strategy which is demonstrated in Table VI.

TABLE VI. Considered Fuzzy Rules

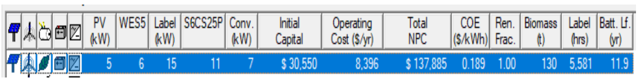
IF					THEN	
PV	wind	biogas	LD	SOC	Po	Battery NU-C-DC
AL L TI ME	L/L/L/L/ L/L/L/L/ L/L/L/L/ L/L/L/M /M/M/M	M/M/M/ M/M/M/ M/H/H/H/ H/H/H/H/ H/M/M/M	L/L/L/ M/M/ H/H/L /L/L/ M/M/	L/M/ H/L/ M/M/ H/L/ M/H/	S1/S1 /S1/S 5/S5/ S5/S5 /S1/S	S1/S 1/S1/ S2/S 2/S3/ S3/S

NA	/M/M/M /M/M/M /M/M/M /M/M/M /M/H/H/ H/H/H/ H/H/H/ H/H/H/ H/H/H	/M/M/M/ M/M/H/H /H/H/H/H /H/H/H/M /M/M/M/ M/M/M/H /H/H/H/H /H/H	M/H/ H/L/L/ L/M/ M/M/ H/H/L /L/L/ M/M/ M/H/ H/H/L /L/M/ M/H/ H/H/L /L/M/ M/H/ H/H	L/M/ H/M/ H/L/ M/H/ L/M/ H/M/ H/L/ M/H/ L/M/ H/L/ M/H/ L/M/ L/M/ L/M/ H/L/ M/L/ M/L/ M/H	1/S1/ S5/S5 /S5/S 5/S5/ S1/S1 /S1/S 1/S1/ S1/S5 /S5/S 1/S1/ S1/S1 /S1/S 1/S5/ S5/S5 /S1/S 1/S1/ S1/S5 /S5/S 5/S1/ S1/S1 /S1/S 5/S5/ S5	1/S1/ S1/S 2/S2/ S1/S 3/S3/ S2/S 2/S1/ S1/S 1/S1/ S3/S 3/S2/ S2/S 1/S1/ S1/S 1/S2/ S2/S 1/S2/ S2/S 2/S2/ S1/S 1/S1/ S2/S 2/S2/ S2/S 2/S2/ S1
AL L TI ME M	L/L/L/L/ L/L/L/L/ L/L/L/L/ L/L/L/L/ L/M/M/ M/M/M/ M/M/M/ M/M/M/ M/M/H/ H/H/H/ H/H/H/ H/H/H/ H/H	M/M/M/ M/M/M/ M/H/H/H/ H/H/H/H/ H/M/M/M /M/M/M/ M/H/H/H/ H/H/H/M/ M/M/M/ M/M/H/H /H/H/H/H	L/L/L/ M/M/ H/H/L /L/L/L /L/M/ M/M/ L/L/L/ L/L/M /M/H/ H/H/L /L/M/ M/H/ H/L/L/ M/M/ H/H/L /L/M/ M/H/ H	L/M/ H/L/ MM/ H/L/ M/L/ M/H/ L/M/ H/L/ M/L/ M/L/ M/H/ L/M/ L/M/ L/M/ L/M/ L/M/ L/M/ L/M/ L/M/ L/M	S3/S3 /S3/S 6/S6/ S6/S6 /S3/S 3/S6/ S3/S3 /S6/S 6/S6/ S3/S3 /S3/S 3/S6/ S6/S3 /S3/S 3/S3/ S3/S6 /S6/S 3/S3/ S3/S3 /S6/S 3/S3/ S3/S3 /S3/S 6/S3	S2/S 2/S1/ S2/S 2/S3/ S3/S 2/S2/ S2/S 3/S3/ S1/S 1/S1/ S2/S 2/S2/ S2/S 2/S2/ S3/S 2/S2/ S2/S 2/S2/ S2/S 2/S2/ S1/S 2/S2/ S3/S 2/S2/ S2/S 2/S2/ S3
AL L TI ME H	L/L/L/L/ L/L/L/L/ L/L/L/L/ L/L/LM/ M//M/M /M/M/M /M/M/M /M/M/M /H/H/H/ H/H/H/	M/M/M/ M/M/M/ M/H/H/H/ H/H/H/H/ H/M/M/M /M/M/M/ M/H/H/H/ H/H/H/M/ M/M/M/ M/M/M/H	L/L/M /M/M/ H/H/L /L/M/ M/M/ H/H/H /L/L/ M/M/ H/H/H /L/L/	L/M/ L/M/ H/M/ H/L/ M/L/ M/H/ L/M/ H/L/ M/L/ M/L/	S3/S3 /S3/S 3/S3/ S6/S6 /S3/S 3/S3/ S3/S3 /S6/S 6/S3/ S3/S3	S2/S 2/S2/ S2/S 1/S3/ S3/S 2/S2/ S2/S 2/S1/ S2/S 2/S3/
	H/H/H/ H/H/H/ H/H	/H/H/H/H /H/H	M/M/ H/H/L /L/M/ M/H/ H/H/L /L/M/ M/H/ H/H	M/H/ L/M/ L/M/ L/M/ L/M/ L/M/ L/M/ H/L/ M/L/ H/L/ M/H	/S3/S 3/S6/ S3/S3 /S3/S 3/S3/ S3/S6 /S3/S 3/S3/ S3/S3 /S6/S 3/S3/ S3/S3 /S3/S 3/S6/ S3/S3	S2/S 2/S2/ S2/S 1/S3/ S3/S 2/S2/ S2/S 2/S2/ S3/S 2/S2/ S2/S 2/S2/ S3/S 3/S2/ S2/S 2/S1/ S2/S 3/S3

VI. Result & Analysis

A. *Evaluation of HOMER for Management System*

Sensitive result from the simulation based on the resource data and input parameters is demonstrated in Fig.22.



PV (kW)	WES5	Label (kW)	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biomass (t)	Label (hrs)	Batt. Lf. (yr)
5	6	15	11	7	$ 30,550	8,396	$ 137,885	0.189	1.00	130	5,581	11.9

Figure 22. Homer optimization based sensitive result.

Optimization result shows that the contribution of solar power is 14%, wind generated power is 12% and biogas generated power is 73% in HREMS. Fraction of consumption by the AC loads is 95% while excess energy fraction is 5% in the system. Account of energy production and consumption per year from the optimization result is indicated in Table VII.

TABLE VII. Electric Energy Production & Consumption Parameters

Production	*kWh/yr*	*Fraction in %*	*Consumption*	*kWh/yr*	*Fraction %*
PHOTOVOLTAIC Module	9014	14	AC primary load	56940	95
Wind turbines	7955	12	Extra	3226	5
Biogas generator	46947	73			
Total	63916	100	Total	60166	100

Average production of electricity for different months of the year is presented in Fig. 23. Generation of energy from wind turbine is notably high in June to August whereas lower amount of energy is produced in October to January. Figure also shows that the photovoltaic power is high during March to May as solar radiation is high in that period of the year. Additionally, generated power from biogas generator is high on August, September and October.

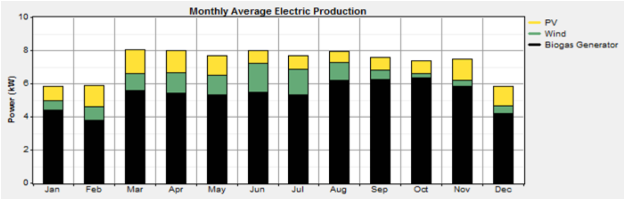


Figure 23. Average production of electricity-month to month.

The cost of HREMS installation is $137,885 which is estimated for fifteen years. Hence, yearly installation cost is $9192.33. Total load demand is 156kWh per day. Annual load demand is 56940 kWh. Per unit cost for the proposed hybrid system is about $0.16143 or 13.72 BDT. Net present cost for each component is shown in Fig. 24.

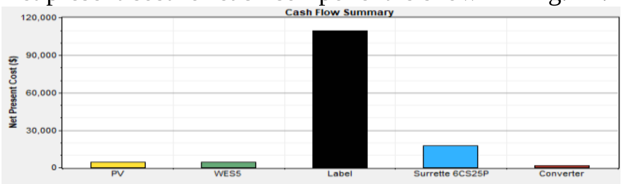


Figure 24. Summary of net present cost for each component (HREMS).

TABLE VIII. COMPARATIVE ANALYSIS OF DIFFERENT MODELS BASED ON ECONOMIC PARAMETERS

System Description	Total Installation Cost ($)
Biogas Model	144,034.00
Photovoltaic-Biogas Model	141,315.00
Wind-Biogas Model	139,418.00
HREMS Model	137,885.00

B. Evaluation of Photovoltaic MPPT

Proposed photovoltaic MPPT system has improved system response as Genetic algorithm has been used for optimization of PID controller. Approached constant voltage MPPT boost converter has been able to extract maximum power from solar panel by maintaining maximum power point voltage at any given time and under voltage fluctuation condition. It also shows the increase in efficiency while comparing with other prevailing methods. The response of the MPPT system has been checked before tuning with GA. After forming transfer function model, response is checked using MATLAB system identification tool. There is high percentage of overshoots and oscillation in the system which is shown in Fig. 25. Fig. 26 represent a graph after tuning MPPT with genetic algorithm.

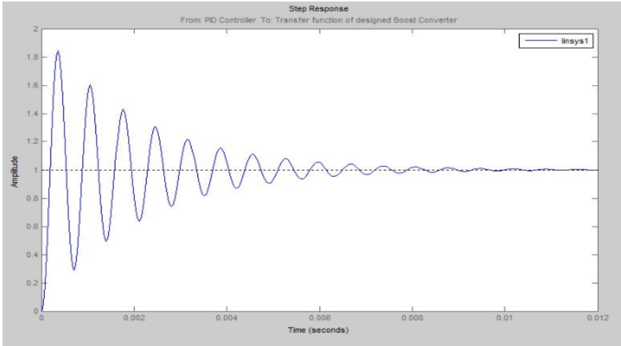


Figure 25. Response of MPPT before tuning with genetic algorithm

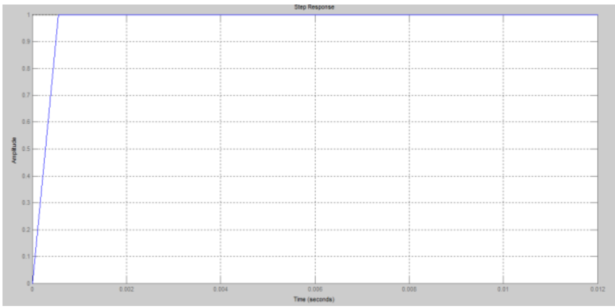


Figure 26. Response of MPPT after tuning with genetic algorithm.

Again, the response of the MPPT system has been monitored after tuning with genetic algorithm. Genetic algorithm optimization tool was employed to update the PID parameters for improving the response by continuously checking for generation after generation and it shows the percentage of overshoots declined to zero and nearly no oscillation in the system which is shown in Fig. 27. Response parameters has been checked before optimization which shows rise time is 8.466e-05, settling time is 0.0080s, settling min is 0.1063, settling max is 0.9437 and overshoot is 88.7326%. Result view from the MATLAB command window is shown in Fig. 28.

Command Window

```
sys2 =

     1


sys3 =

               1
  ------------------------------
  1.245e-08 s^2 + 1.2e-05 s + 2

Continuous-time transfer function.


ans =

        RiseTime: 8.4666e-05
    SettlingTime: 0.0080
     SettlingMin: 0.1063
     SettlingMax: 0.9437
       Overshoot: 88.7326
```

Figure 27. GA-PID MPPT system response parameters before optimization.

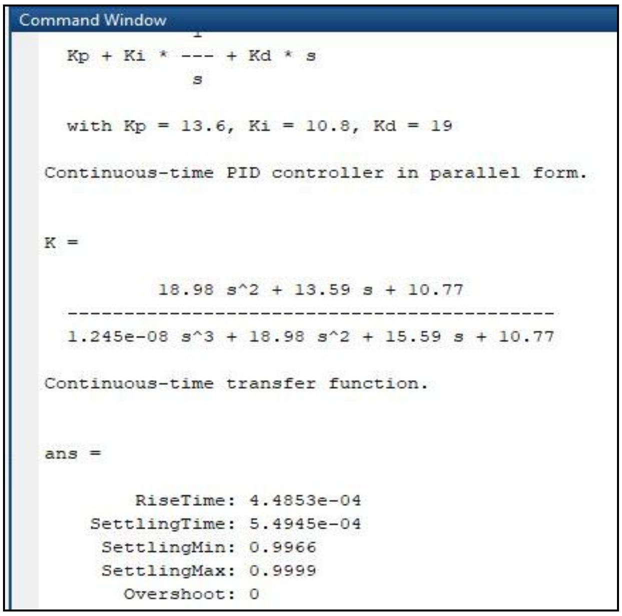


Figure 28. GA-PID MPPT system response parameters after optimization.

Again, response parameters has been checked after optimization which shows rise time is 4.485e-04, settling time is 5.4945e-04s, settling min is 0.99, settling max is 0.99 and overshoot is 0%. Result view from the MATLAB command window is shown in Fig.28. Power extraction at different weather conditions has been shown in the Table IX. When solar irradiance are 1000 W/m^2 (25°C), 700 W/m^2 (24°C), 680 W/m^2 (18°C), 680 W/m^2 (28°C), 650 W/m^2 (30°C), 550 W/m^2 (24°C), 580 W/m^2 (26°C), then output power values with mppt are 70.73W, 69.2W, 68.56W, 67.02W, 61.38W,52.19W, 56.21W respectively.

TABLE IX. POWER EXTRACTION AT DIFFERENT WEATHER CONDITIONS

Irradiance(W/m2)	Temp (◦C)	Vout	Iout	Pout
1000	25	22.51 V	3.126 A	70.73 W
700	24	22.32 V	3.101 A	69.2 W
680	18	22.22 V	3.086 A	68.56 W
680	28	21.97 V	3.051 A	67.02 W
650	30	21.02 V	2.92 A	61.38 W
550	24	19.39 V	2.692 A	52.19 W
580	26	20.12 V	2.794 A	56.21 W

Proposed method has been compared with other ANFIS based MPPT which is shown on the Table X. ANFIS based MPPT has 88.57% static efficiency whereas proposed GA-PID based MPPT has 94.30% efficiency on average. Efficiency of the system is calculated based on the ratio of obtained power (Po) by using MPPT method to the rated maximum power (Pmax) from panel. Proposed method also has good transient response and cost effectiveness than other method.

TABLE X. COMPARISON OF GA-PID METHOD WITH ANFIS BASED METHOD AT STC (1000 W/M2, 25°C)

MPPT Methods	Po	Pmax	Static Efficiency	Fitness Value	Epoch /Generation
ANFIS based MPPT [28]	71.94 W	80 W	88.57%	0.079	300
Proposed GA-PID	70.73 W	75 W	94.30 %	0.0123	58

C. Evaluation of Energy Management Strategy

This energy management strategy includes 130 fuzzy rules. From the result of optimization we find the use of 5kW photovoltaic, 15kW wind turbine plus 15kW biogas generator. Highest possible generation of power from the renewable sources is 35 kW.

Fig. 29 shows the output surface view of Po with respect to generated power from photovoltaic module and SOC of battery. Three dimensional view of the surface has photovoltaic power generation prediction in the X axis. Battery SOC is appeared in Y axis while z axis shows the output power (Po). Parameters on the axes correspond to each other depending on fuzzy rules.

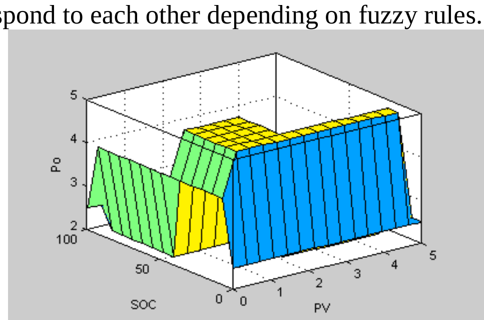


Figure. 29. Generated power of photovoltaic.

Fig. 30 shows the output surface view of Po with respect to generated power from wind and SOC of battery. Three dimensional view of the surface has wind power generation prediction in the X axis. Battery SOC is appeared in Y axis while z axis shows the output power (Po). Parameters on the axes correspond to each other depending on fuzzy rules.

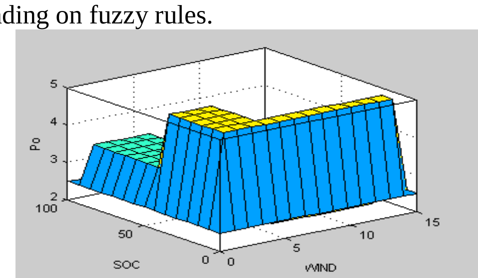


Figure 30. Generated power of wind turbine.

Fig. 31 shows the output surface view of Po with respect to generated power from biogas generator and SOC of battery. Three dimensional view of the surface has biogas generated power prediction in the X axis. Battery SOC is appeared in Y axis while z axis shows the output power (Po). Parameters on the axes correspond to each other depending on fuzzy rules.

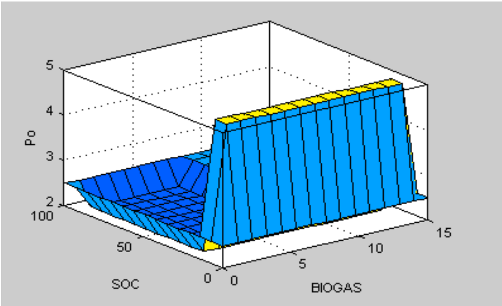


Figure 31. Generated power of biogas generator.

Fig. 32 shows the output surface view of battery status from fuzzy logic controller. Three dimensional view of the surface has power generation from wind prediction in the X axis. Load demand is appeared in Y axis while z axis shows the battery charge discharge status (Battery-NU-C-DC).

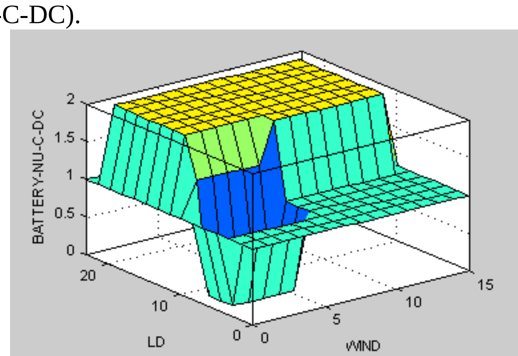


Figure 32. Battery status.

Case study-1

Fig. 33 shows that when PV-NA, Wind-L, Biogas-M, LD-M, SOC- L, Then Po-(S1-0), Battery-NU (S1- 0).

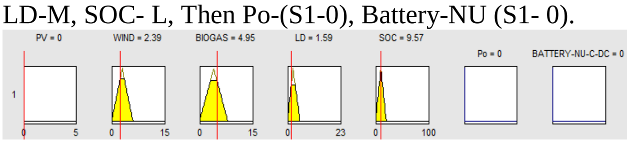


Figure 33. When PV-NA, Wind-L, Biogas-M, LD-M, SOC-L.

Case study-2

Fig. 34 shows that when PV-NA, Wind-L, Biogas-M, LD-M, SOC-M Then Po-(S5-4), Battery-C (S2-1)

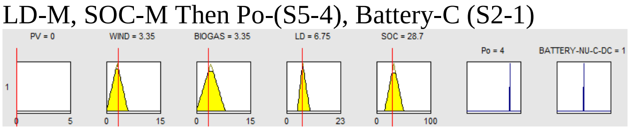


Figure 34. When PV-NA, Wind-L, Biogas-M, LD-M, SOC-M.

Case study-3

Fig. 35 shows that when PV-L, Wind-L, Biogas-M, LD-L, SOC-L Then Po-(S3-2), Battery-C (S2-1)

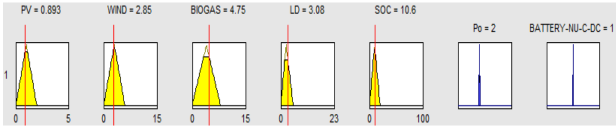


Figure 35. When PV-L, Wind-L, Biogas-M, LD-L, SOC-L.

Case study-4

Fig. 36 shows that when PV-L, Wind-L, Biogas-H, LD-M, SOC-L Then Po-(6-5), Battery-C (S2-1)

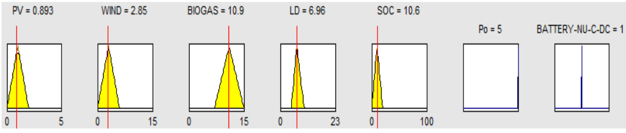


Figure 36. When PV-L, Wind-L, Biogas-H, LD-M, SOC-L.

Case study-5

Fig. 37 shows that when PV-H, Wind-L, Biogas-M, LD-H, SOC-M Then Po-(S6-5), Battery-DC (S3-2)

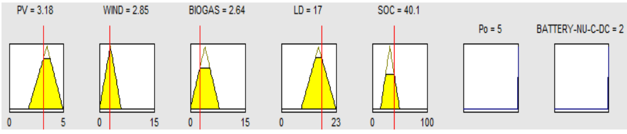


Figure. 37. When PV-H, Wind-L, Biogas-M, LD-H, SOC-M.

V. Conclusion

Proposed HREMS is designed and optimized for a small market consists of 26 small shops. Estimated life time of the system is 15 years and considered interest rate is 6%. The management system includes one mppt method to bring out maximum power from Photovoltaic module based on GA and PID controller. Introduced MPPT method has 97.86% efficiency and less control variable which reduces the data acquisition cost of the system. The rise time is 4.485e-4 and overshoot is 0% after optimization which shows the improvisation in system response. Contribution of the solar, wind and biogas to the HREMS are 14%, 12% and 73% respectively in terms of electricity generation. FLC controls the power flow within the system depending on 130 knowledge based fuzzy rules. Switching based fuzzy rules can handle wide range of operation conditions and minimizes the power loss according to load demand and availability of resources. Optimized HREMS shows 3.13% cost savings and about 99% reduction in carbon emission. Additionally, Battery SOC is maintained at a rational level of 10% to 95% for extending battery life and use of municipal waste assists in retrenchment of landfill problem. Overall, simulation results exhibit excellent performance which is suitable for the selected area and it can be applied in other prospective regions.

Conflict of Interest

The authors announce that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

Nesar Uddin supported the research and helped to write the paper. Dr. Md Saiful Islam and Dr. Md Tazul Islam guided the research. All authors had permitted the final version.

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