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SMART HYBRID ENERGY MANAGEMENT SYSTEM USING FUZZY LOGIC

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Abstract -Energy consumption has increased exponentially since the start of the new millennia. The arrival of the smart grid era has led to renewable energies such as sun, wind, water etc. being harnessed to help achieve energy supply and demand. This paper proposes a Smart Hybrid Energy Management System (SHEMS) which can be easily installed and is implemented using Fuzzy Logic based on various parameters such as time, load size, grid availability, battery status. SHEMS architecture consists of an integrated battery and load management system. The proposed architecture is expected to optimize the energy consumption and save energy costs.

***Key Words*:**Energy Consumption, Smart hybrid energy management system (SHEMS), Fuzzy Logic, Battery management, Load management, Architecture, Optimize.

1.INTRODUCTION

Over the years traditional energy sources have been used in the manufacture of electrical energy. Due to the decrease in the supply of these energy resources, electricity prices are increasing. Thermal power plants and nuclear power plants are the major energy sources that cause global warming, and production of nuclear waste that is hazardous to any living on earth.

In recent years, the implementation of modernized smart city infrastructure has become a global shared goal in most countries due to the tremendous environmental, economic and social benefits it could bring. Building renewable and storage energy sources built in residential premises can be integrated into SHEMS in tandem with the increasing growth of advanced power electronics and green energy technologies to increase the in-house performance of energy conversion and usage.

2. SMART HYBRID ENERGY MANAGEMENT SYSTEM (SHEMS)

Smart Hybrid Energy Management System (SHEMS) as discussed in [4] is a vital home system for successful demand-side smart grid management. It monitors and arranges various home appliances in real-time, based on user preferences in smart houses via the human-machine interface to conserve electricity costs and improve energy efficiency utilization. With growing concerns about global energy security and environmental emissions, more and more distributed renewable generations, such as wind turbines, solar panels, and plug-in electric vehicles (PEVs), etc., would be grid-integrated with gradually increasing penetration into active distribution networks as shown below in Figure-1.

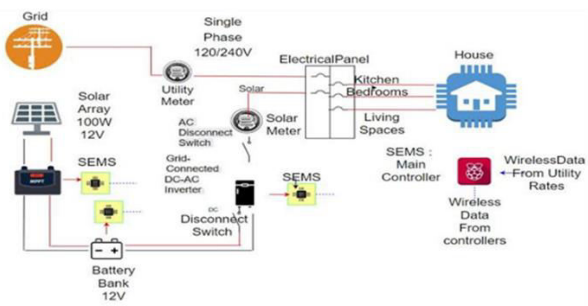


Figure-1: Block Diagram of General SHEMS Architecture (Courtesy: Internet)

As discussed in [2,3], each home has two energy-related parts: consumption and generation. The energy usage component involves various home appliances and lamps. The energy generation component comprises renewable energies such as solar and wind energy. Because a home consumes and generates energy, to minimize the energy cost, a control device like a home server needs to monitor and control both energy consumption and energy generation.

SHEMS monitors medium and light charges and determines whether the load should be connected to the battery or grid. Installed in the premises is a renewably energized battery bank. The battery bank provides medium- and light-load power. The grid is always connected to heavy loads. The power consumed by the loads is sensed, processed and displayed on a webpage where the user can easily create control. SHEMS is the Master Controller and manages the activities of the whole Energy Management system as shown in the Figure-2 below.

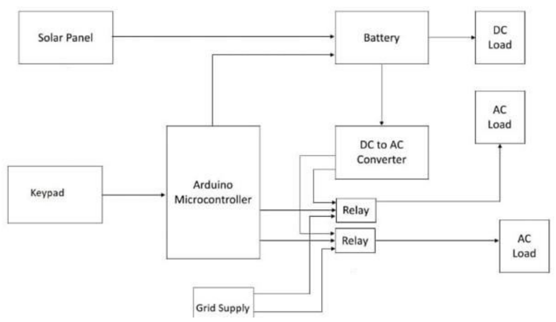


Figure-2: Block Diagram of Proposed SHEMS Framework

2.1 SPECIFICATIONS OF PROPOSED SYSTEM

The SHEM framework as shown in Figure-2 is made using the following components. Specifications of the proposed framework is given in Table-1.

Table-1: Specifications of Proposed System

Equipment	Details
Arduino Mega	The **Arduino Mega 2560** is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.
ACS712-05BT Sensor	• Low-noise analog signal path • Total output error 1.5% at TA = 25°C • Small footprint, low-profile SOIC8 package • 1.2 mΩ internal conductor resistance • 2.1 kVRMS minimum isolation voltage from pins 1-4 to pins 5-8 • 5.0 V, single supply operation • 185 mV/A output sensitivity • Output voltage proportional to AC or DC currents • Factory-trimmed for accuracy • Extremely stable output offset voltage • Nearly zero magnetic hysteresis
Battery	Voltage: 12V DC at 4.5 Ah
Lamps	Voltage: 230V with variable resistance to depict appliances
Relay	• Trigger Voltage (Voltage across coil) : 5V DC • Trigger Current (Nominal current) : 70mA • Maximum AC load current: 10A @ 250/125V AC • Maximum DC load current: 10A @ 30/28V DC • Compact 5-pin configuration with plastic moulding • Operating time: 10msec Release time: 5msec
Solar Panel	Voltage: 12V DC at 0.5A
Inverter	12V DC to 230V AC at 200 Watts.
Keypad	12-input phone keypad

2.2 METHODOLOGY

Fuzzy logic systems are based on logical reasoning along with the ability to fuzzify any system that makes it easier to execute. Fuzzy Logic Controllers are used in many industrial processes because of which control activity takes place like human and the control process were easy once built.

To build the controller, number of parameters need to be selected and then membership function and rules based on heuristic information are selected as explained in [4]. The SHEM Framework has four input membership functions and one output membership function. Totally five membership functions are designed based on the parameters i.e. Time, Load, Grid Availability and Battery Status.

2.3 IMPLEMENTATION

In Proteus Design Suite the real-time implantation is done using Schematic Capture. Proteus Programming Suite is a proprietary suite of software tools mainly used for automating electronic programming. The software is primarily used by electronic design engineers and technicians to build schematics and electronic prints for printed circuit board manufacture.

Proteus software uses schematic capture, both for simulation design and as the design process of a PCB layout project. It is also a central feature and integrated into all product setups.

Simulation works by either adding a hex file or debug file to the schematic portion of the microcontroller. Then, it is simulated with any related analog and digital electronics. This makes its use in fields such as engine control, temperature control and user interface design in a wide range of project prototyping. It also finds use in the general community of hobbyists and is convenient to use as a training or teaching tool, since no hardware is required.

3.LITERATURE SURVEY:

[1] “Fuzzy Logic Based Smart Home Energy Management System”:
Authors propose a Smart Home Energy Management System (SHEMS) that can be installed in a consumer void of technological upgradations is proposed in this paper. A prototype consisting of an integrated Battery Management and Load Management System is designed and developed. The Battery management system connects the battery either to the load or for charging, while the Load Management System decides whether the load should be connected to the grid or the battery based on different parameters like type of load, battery status and grid availability. The energy management system is implemented using Fuzzy logic and the hardware model is evaluated for different test conditions. The significant improvement in the energy consumed with and without SHEMS is presented.

[2] “Smart Home Energy Management System Including Renewable Energy Based on ZigBee and PLC”:
In this paper a Smart HEMS architecture is proposed which simultaneously considers both energy consumption and generation. The energy measuring modules based on ZigBee are used to monitor the energy consumption of home appliances and lights. A renewable energy portal based on PLC is used for monitoring the renewable energy generation. The home server gathers the data on energy consumption and generation, analyses them for estimation of energy, and controls the schedule of home energy use to minimize energy costs. The remote energy management server aggregates, compares, and generates useful statistical analysis information, the energy data from numerous home servers. The proposed HEMS architecture is expected to optimize home energy usage by considering both energy consumption and generation, and result in cost savings for home energy.

[3] “Smart Home Automation System Using Wi-Fi Low Power Devices”:

This paper proposes a smart home automation system which ensures security and makes life easier for the user. It contains a large number of sensors that are capable of controlling or monitoring objects distributed in 3D space. The sensors can be customized to calculate temperature, humidity, sound, light, noise, dust air, etc. The paper deals with a solution proposed to turn a typical house into a smart house while reducing the energy consumption. This can be achieved using wireless sensor networks and the LabVIEW graphical programming environment, which use the NI LabVIEWTM Statechart module to collect sensor data.

[4] “Smart home energy management systems: Concept, configurations, and scheduling strategies”:

The paper presents a short description of the smart HEMS architecture and functional modules. Then, in smart houses, the advanced HEMS infrastructures and home appliances are extensively studied and tested. In addition, the use of various renewable energy building services in HEMS, including solar, wind, biomass, and geothermal energy, is being surveyed. Finally, various home appliance scheduling techniques are also being studied to reduce the cost of residential electricity and increase the energy output from power generation utilities.

4. FUZZY LOGIC CONTROLLER

A fuzzy control system is a fuzzy logic-based control method:- a mathematical method that analyses analog input values in terms of logical variables that take on continuous values between 0 and 1, as opposed to classical or modern logic, which acts on binary values of either 1 or 0 (true or false), respectively.

4.1 OVERVIEW

Fuzzy logic is found widely in control devices. The word 'fuzzy' refers to the fact that the logic in question is capable of dealing with ideas that cannot be represented as 'true' or 'false' but rather as 'partly true.' While alternative approaches such as genetic algorithms and neural networks can do nearly as well as fuzzy logic in certain cases, fuzzy logic has the advantage that the issue can be approached in terms that human operators c It allows the mechanization of tasks that people already do effectively.

4.2 DEVELOPMENT OF FUZZY LOGIC CONTROLLER

The variable which can represent the dynamic performance of the plant to be controlled should be chosen as the input to the controller to design the Fuzzy Logic Controller (FLC). The variables for input and output are converted to Linguistic variables.

4.3 SELECTION OF THE TRINGULAR AND TRAPEZOIDAL MEMBERSHIP FUNCTIONS

Triangle and trapezoidal are chosen for the design of the membership function. The justification in Fuzzy Logic Controller for selecting the triangular and trapezoidal membership function is as follows:

1. To define the membership function, small amounts of data are required.
2. Quick adjustment of membership parameters (modal values) functions based on measured input values —-> output of a system.
3. The possibility to obtain input mapping — > output of a model that is a hypersurface consisting of linear segments.
4. Polygonal membership functions mean the condition of a unity partition (meaning the sum of membership grades for each value x is 1) is easily met.

4.4 MEMBERSHIP FUNCTION OF THE FUZZY LOGIC CONTROLLER

The membership functions of the Fuzzy Logic Controller are implemented using eFLL library.

1. Membership function of the input variable Time

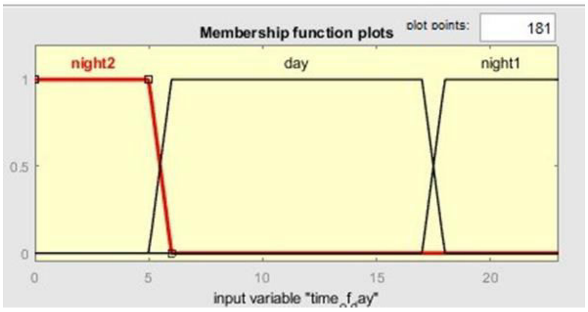


Figure-3: Membership function for the input variable Time

Time consists of three subsets of data i.e. night_2(0-5 hrs), day (6-17 hrs), night_1(18-23 hrs).

2. Membership function of the input variable Load

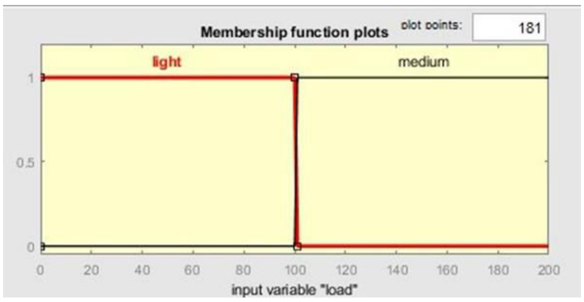


Figure-4: Membership function for input variable Load

Load membership function consists of two subsets that is light (0-100 watts) and medium (101-200 watts).

3. Membership function of the input variable Grid availability

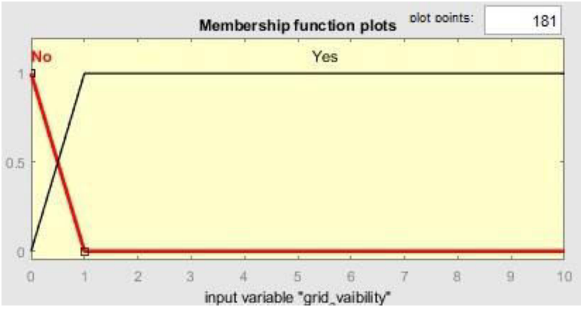


Figure-5: Membership function for input variable Grid Availability

Grid membership function consists of two subsets i.e. No (0 V) And Yes (1-250 V)

4. Membership function of the input variable Battery Status

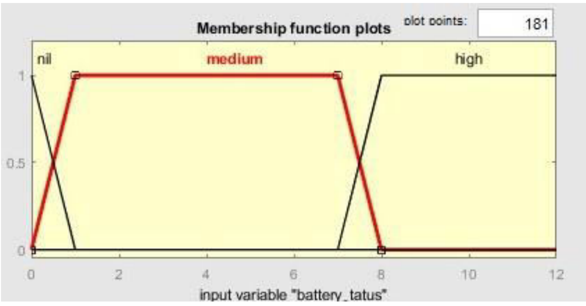


Figure-6: Membership function for input variable Battery Status

5.Membership function for the output variable showing controller output:

For the Fuzzy Logic Controller, the membership function of the output variable of and the degree of membership function are shown in Figure below

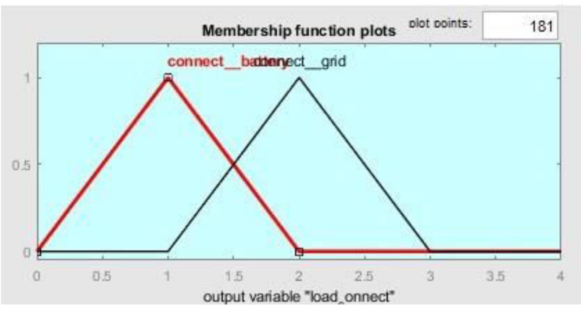


Figure-7: Membership function for Output variable Load Connection

4.5 RULE BASE TABULATION OF THE FUZZY LOGIC

The table-2 shows Time, Load, Grid availability and Battery status variables and their various combinations which produces the change in the control signal for the fuzzy rule base i.e. Relay Output/Load Connection. Rule Base matrix logic was referred Krishna Prakash N. [1].

Examples of some rule bases are listed as follows:

- If Time is Day and Load is Light and Grid is Yes and Battery Status is High then controller output will be Connect Battery.
- If Time is Day and Load is Medium and Grid is No and Battery Status is Nil then controller output will be Connect Grid.
- If Time is Night and Load is Light and Grid is Yes and Battery Status is High then controller output will be Connect Battery.

Example: If Time is Night and Load is Medium and Grid is No and Battery Status is Medium then controller output will be Connect Grid.

Time of Day	Load Type	GRID	Battery Status	Relay Output
Day (6 am -6 pm)	Light load	Yes	High	Connect Battery
			Medium	Connect Battery
			Nil	Connect Grid
		No	High	Connect Battery
			Medium	Connect Battery
			Nil	Connect Grid
	Medium load	Yes	High	Connect Battery
			Medium	Connect Battery
			Nil	Connect Grid
		No	High	Connect Battery
			Medium	Connect Grid (Default)
			Nil	Connect Grid (Default)
Night (6 pm - 6 am)	Light load	Yes	High	Connect Battery
			Medium	Connect Grid
			Nil	Connect Grid
		No	High	Connect Battery
			Medium	Connect Battery
			Nil	Connect Grid
	Medium load	Yes	High	Connect Grid
			Medium	Connect Grid
			Nil	Connect Grid
		No	High	Connect Battery
			Medium	Connect Grid (Default)
			Nil	Connect Grid (Default)

Table-2: Rule base tabulation of the Fuzzy Logic Controller

5. IMPLEMENTATION OF SYSTEM THROUGH PROTEUS DESIGN SUITE AND ARDUINO IDE

5.1 ARDUINO IDE

The Arduino Integrated Development Environment-or Arduino software (IDE)-contains a text editor for code writing, a message field, a text screen, a toolbar with common function buttons and a set of menus. It connects to and interacts with Arduino and Genuino Hardware to upload programs.

5.2 PROTEUS DESIGN SUITE

The Proteus Design Suite is a proprietary suite of software tools mainly used for automating electronic development. The software is primarily used by computer design engineers and technicians to create schematics and computer prints for printed circuit board manufacture.

Schematic capture in the Design Suite is used both for the design simulation and for the production process of a PCB

model project. It is thus an integral part of all product configurations which are included.
The simulated microcontroller works in proteus by using the schematic part with either the hex file or a debug file. It is then co-simulated with any connected analog and digital electronics.

5.3 SIMULATION USING PROTEUS DESIGN SUITE

The Proteus Design Suite is used to create a virtual background of the SHEM framework as shown below in the Figure-8;

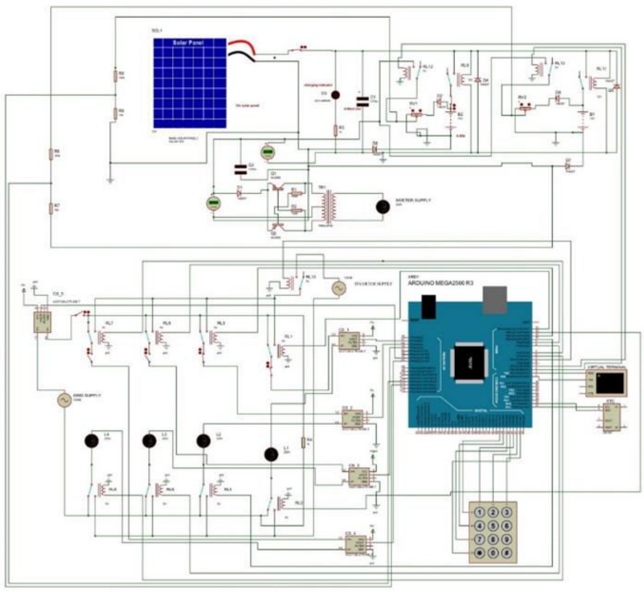


Figure-8: Schematic Diagram of SHEM System

The architecture concept was referred from Krishna Prakash N. [1]. Framework consists of an Arduino Mega 2560, ACS71205-BT Sensors, RTC module (DS1307), Solar panel, battery, inverter, keypad, lamps to depict Household appliances and relays to control the power supply switching.

For Demonstration purposes, a simple inverter is used and its output is replaced by an AC supply to depict the working of High Wattage inverter.

5.4 CIRCUIT DIAGRAM

In the Figure-8 as depicted, solar panel is connected to two batteries B1 and B2 respectively through an Auto charging relay. The Voltage status of the same are maintained by using potentiometers RV1 and RV2, to mimic draining and charging, the voltage level of each battery is detected by using voltage divider circuits whose outputs are connected to A12 and A13 of the Arduino. DC power is converted into 230V AC using a simple mosfet inverter circuit.

Battery Power Supply is replaced by another ac supply for simulation purposes due to limits on CPU usage. Relays RL1 to RL8 are used for controlling the connections of the loads to either grid or the battery supply. These relays are connected to pins 13 to 6 of the Arduino Mega. ACS712-05BT current sensors are used to measure the current flowing through each component and also to sense the presence of the grid, where output of each sensor is connected to the analog input of the Arduino from inputs A1 to A5.DS1307 RTC module is connected to the Arduino through the SDA and SCL pins (20 and 21) of the Arduino Mega. A 12 key keypad is also connected to Arduino for user input through the digital pins 29 to 23.

5.5 WORKING

The RTC module DS1307 is set to the current clock time and the hour value from the same is taken as time input. Battery Status is derived by using two voltage divider circuits with resistors R6(100K) and R7(10K) For Battery B1and resistors R8(100K) and R9(10K) for Battery B2. The analog input from the voltage dividers is then given to A12 and A13 port of the Arduino. The battery voltage found is then fed to Battery management function called batcondition().The function's task is to select one battery out of the two with the lower voltage as the source to preserve and prevent over drainage during blackouts. As when the selected battery gets depleted, it switches to the second while it charges. Battery drain is shown using potentiometers RV1 and RV2 to change the battery's output voltage.

Load is calculated using ACS71205-BT, a Fully Integrated, Hall Effect-Based Linear Current Sensor with 2.1 kVRMS Voltage Isolation and a Low-Resistance Current Conductor. Using the ACS712.h inbuilt functions getCurrentAC() we obtain the current flowing through each appliance(AC Lamp) and calculate the power consumed by each appliance and the total.

Meanwhile one of the current sensors is used to measure the presence of Grid supply by detecting whether there is current following through or relays and a resistor R4(1K). To depict the Grid availability, we use a switch. The said inputs obtained are passed through the fuzzy engine created through the eFLL functions created for Fuzzy Logic implementation. The Real time input is mapped into the fuzzy rule matrix based on fuzzy set created for each fuzzy input.

Rule base matrix then connects the respective output of the said input and converts it into a crisp set based on the rule executed. If none of the rules are met then 0 is returned as crisp output. Values 1, 2 are used to connect the relay of the appliances either to Grid or Battery respectively.

A fail-safe code is built into the algorithm to make sure that if the load isn't supported by battery during power outage, the user we be given a warning about it and will be recommended to switch certain appliances to try again. Battery will be used during measuring when the grid is not available.

6. NEED FOR FUZZY LOGIC

The performance of Fuzzy Logic Controller (FLC) is compared with conventional *IF-ELSE LOGIC* Controller. Below mentioned points are the pros and cons of using Fuzzy Logic Controller over *IF-ELSE LOGIC* Controller

Pros of Fuzzy Logic Controller compared to if-else logic

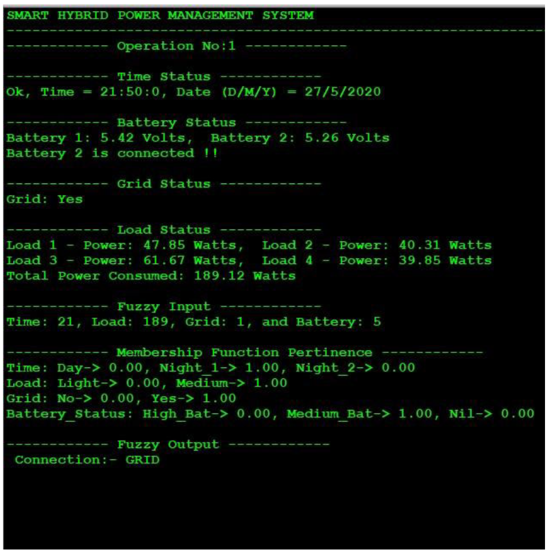
- Fuzzy controllers are real time expert system implementing human experiences andknowledge, which can't be realized by *IF-ELSE LOGIC*.
- Fuzzy controllers are heuristic modular way for defining any nonlinear control system. This flexibility is absent in *IF-ELSE LOGIC*.
- From sufficient knowledge of system, FLC can achieve a higher degree of automation and can go far beyond any conventional controllers with the use of Neural network and genetic algorithm.
- Fuzzy logic requires less line of codes compared to *IF-ELSE LOGIC* and it can handle unexpected situation which the programmer did not think of.
- With proper knowledge of Fuzzy Logic will reduce the time consumed and work for coding by the programmer covering a wide range of conditions that will take *IF-ELSE* a lot of coding to cover.

Cons of Fuzzy Logic Controller compared to *IF-ELSE LOGIC* controller:

- Expertise of knowledge has to be available all time.
- It is not clearly understood and has no standard tuning and no stability criteria.
- It cannot be implemented for unknown system of no information, i.e. the system which has never been executed in past.

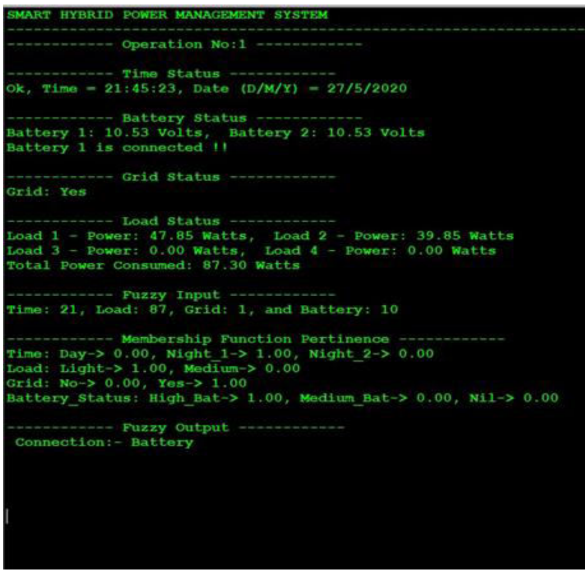
7. RESULT AND SIMULATION

The simulation result of Fuzzy Logic Controller with random input using Proteus Design Suite as shown in the Figures 9,10,11 and 12.



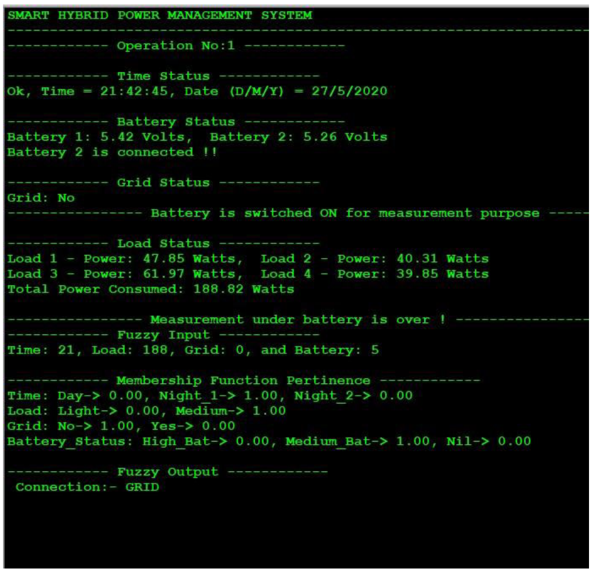
```
SMART HYBRID POWER MANAGEMENT SYSTEM
------------ Operation No:1 ------------

------------ Time Status ------------
Ok, Time = 21:50:0, Date (D/M/Y) = 27/5/2020

------------ Battery Status ------------
Battery 1: 5.42 Volts,  Battery 2: 5.26 Volts
Battery 2 is connected !!

------------ Grid Status ------------
Grid: Yes

------------ Load Status ------------
Load 1 - Power: 47.85 Watts,  Load 2 - Power: 40.31 Watts
Load 3 - Power: 61.67 Watts,  Load 4 - Power: 39.85 Watts
Total Power Consumed: 189.12 Watts

------------ Fuzzy Input ------------
Time: 21, Load: 189, Grid: 1, and Battery: 5

------------ Membership Function Pertinence ------------
Time: Day-> 0.00, Night_1-> 1.00, Night_2-> 0.00
Load: Light-> 0.00, Medium-> 1.00
Grid: No-> 0.00, Yes-> 1.00
Battery_Status: High_Bat-> 0.00, Medium_Bat-> 1.00, Nil-> 0.00

------------ Fuzzy Output ------------
 Connection:- GRID
```

Figure-9: Simulation output using virtual terminal tool for night time rule base with grid and medium load with high battery



```
SMART HYBRID POWER MANAGEMENT SYSTEM
------------ Operation No:1 ------------

------------ Time Status ------------
Ok, Time = 21:45:23, Date (D/M/Y) = 27/5/2020

------------ Battery Status ------------
Battery 1: 10.53 Volts,  Battery 2: 10.53 Volts
Battery 1 is connected !!

------------ Grid Status ------------
Grid: Yes

------------ Load Status ------------
Load 1 - Power: 47.85 Watts,  Load 2 - Power: 39.85 Watts
Load 3 - Power: 0.00 Watts,  Load 4 - Power: 0.00 Watts
Total Power Consumed: 87.30 Watts

------------ Fuzzy Input ------------
Time: 21, Load: 87, Grid: 1, and Battery: 10

------------ Membership Function Pertinence ------------
Time: Day-> 0.00, Night_1-> 1.00, Night_2-> 0.00
Load: Light-> 1.00, Medium-> 0.00
Grid: No-> 0.00, Yes-> 1.00
Battery_Status: High_Bat-> 1.00, Medium_Bat-> 0.00, Nil-> 0.00

------------ Fuzzy Output ------------
 Connection:- Battery
```

Figure-10: Simulation output using virtual terminal tool for night time rule base with grid and light load with high battery



```
SMART HYBRID POWER MANAGEMENT SYSTEM
------------ Operation No:1 ------------

------------ Time Status ------------
Ok, Time = 21:42:45, Date (D/M/Y) = 27/5/2020

------------ Battery Status ------------
Battery 1: 5.42 Volts,  Battery 2: 5.26 Volts
Battery 2 is connected !!

------------ Grid Status ------------
Grid: No
---------------- Battery is switched ON for measurement purpose -----
------------ Load Status ------------
Load 1 - Power: 47.85 Watts,  Load 2 - Power: 40.31 Watts
Load 3 - Power: 61.97 Watts,  Load 4 - Power: 39.85 Watts
Total Power Consumed: 188.82 Watts

---------------- Measurement under battery is over ! ---------------
------------ Fuzzy Input ------------
Time: 21, Load: 188, Grid: 0, and Battery: 5

------------ Membership Function Pertinence ------------
Time: Day-> 0.00, Night_1-> 1.00, Night_2-> 0.00
Load: Light-> 0.00, Medium-> 1.00
Grid: No-> 1.00, Yes-> 0.00
Battery_Status: High_Bat-> 0.00, Medium_Bat-> 1.00, Nil-> 0.00

------------ Fuzzy Output ------------
 Connection:- GRID
```

Figure-11: Simulation output using virtual terminal tool for night time rule base withno grid and medium load with medium battery

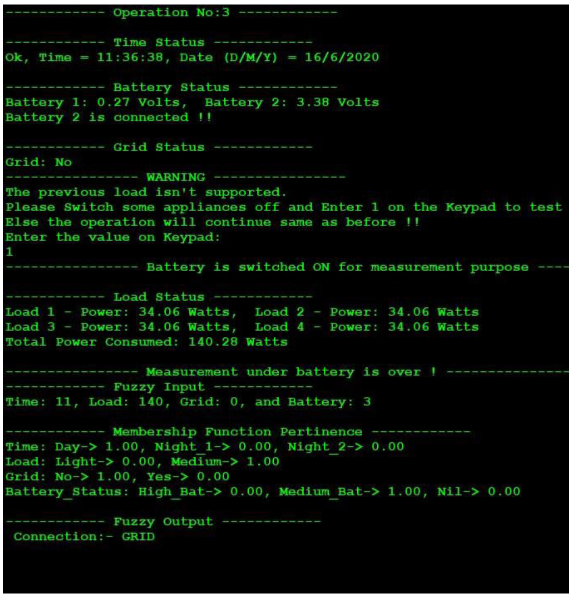


Figure-12: Simulation output using virtual terminal tool forday time rule base withno grid and medium load with medium battery depicting fail safe condition.

VII. CONCLUSION:

As we observe that using fuzzy logic makes our project more robust with few lines of codes but it could be a tedious job for the programmer to implement Fuzzy logic. So, we can also turn to the IF ELSE conditions to make this project a bit easy. Using IF ElSE would make coding much simpler, but can't manage it if any unforeseen situation occurs. The programmer had to bear in mind all potential circumstances that could occur in the future for using If ElSE condition.

In this paper, an attempt is made to carry out automatic conversion of light and medium loads to renewably energized local storage based on its availability while reducing the pressure on the public power grid. Installation of SHEMS at domestic premises would be appreciated when introduced globally in every home. Reduction in the use of domestic electricity plays an important role in reducing the overall carbon content and SHEMS is one of the efficient solutions, as is evident from the results of the comparison presented in this work. Analysis can be achieved by considering in-house profiles that have a larger number of light loads and medium home loads.

VIII. REFFERENCE:

[1] Fuzzy Logic Based Smart Home Energy Management System by Krishna Prakash N., Suraj R Gupta, Shankaranarayanan P.V., Sidharth S, Sirphi M, Department of Electrical and Electronics Engineering Amrita School of Engineering, Coimbatore Amrita Vishwa Vidyapeetham, India, 2018.

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[4] Smart home energy management systems: Concept, configurations, and scheduling strategies by Bin Zhou, Wentao Li, Ka Wing Chan, Yijia Cao, YonghongKuang, Xi Liu and Xiong Wang, College of Electrical and Information Engineering, Hunan University, Changsha, China & Department of Electrical Engineering, The Hong Kong Polytechnic University, Hong Kong, 2016.

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BIOGRAPHIES

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