

Fuzzy Based Energy Management Model for Smart Campus Hybrid Microgrid

¹Ajuzie Uchechukwu.C.,²Azubogu Augustine.C.O., ^{3*}Okafor Chukwunenye.S,⁴Maduka Nosike C.

¹Solar and Power Electronics Department, Electronics Development Institute (ELDI) Awka

^{2,3}Department of Electronic and Computer Engineering Nnamdi Azikiwe University Awka

⁴Department of Physics Federal University Gusau

Corresponding author's Email: cs.okafor@unizik.edu.ng

Abstract - This work presents an energy management model (EMM) for Smart Campus Hybrid Microgrid (CHMG) using fuzzy Logic. The School of Postgraduate Studies (SPGS) sub-grid, in Nnamdi Azikiwe University Awka Campus Anambra State Nigeria was taking as the case study. Four major electrical energy input sources are available to this sub-grid namely; solar photovoltaic (PV), diesel generator, utility grid and auxiliary energy source from neighbouring sub-grids. The electrical loads at the SPGS sub-grid were categorized into high priority (hpl), priority (pl) and less priority (lp) categories. The algorithm that ensures proper selection of available energy sources and corresponding supply to the load categories was developed. The solar plant was modelled using four major states represented by the following fuzzy logic linguistic variables; VERYLOW (12.1V), LOW (12.5V), HIGH (13V) and VERYHIGH (13.5V) depicting the battery voltage of a unit battery. The other energy sources to the microgrid had only two possible states represented by two fuzzy logic linguistic variables; LOW (1-1.5V), and HIGH (4.5-4.9V) and this implies that they are either available or not available. Eleven simple fuzzy rules were used to model both the energy scheduling of the different energy input sources and the load shedding procedure in times of energy shortfall within the sub-grid. The fuzzy logic model was then implemented and simulated in MatLab Simulink using a fuzzy logic controller. Ten different test scenarios were used to test the Simulink model and the system output response was compared with expected system response. It was observed that the Energy Management System (EMS) was able to implement the expected energy management algorithm for the SPGS sub-grid.

Key Words: CHMG, Fuzzy Logic, Hybrid, MatLab, Microgrid (MG)

1. INTRODUCTION

The energy management system (EMS) of hybrid microgrids are very complex systems as they are expected to handle several functions in order to accurately manage the available energy within the microgrids. A robust technology, which is able to integrate all the complexities of energy management of hybrid MG is required to successfully model this EMS. Some of these complex functions include the harnessing of all the available energy sources to the microgrid, making intelligent decisions based on the available energy sources and smartly distributing them to the electrical loads. The categories of electrical loads electricity is supplied to at any time (t) is a function of the states of the available energy input sources. Fuzzy logic was used to develop this Energy Management model, leveraging on its ability to handle the complexities demanded by hybrid MGs, using simple sets of fuzzy rules. The purpose of this model is to develop a reliable cost efficient electricity delivery to the SPGS sub-grid at Nnamdi Azikiwe University Awka Campus. The fuzzy logic EMS modelled is a multi-function intelligent agent termed Localized Intelligent Agent (LIA).

According to [1], a microgrid is a local and independent energy system that generates, distributes, stores and regulates the flow of electricity within the microgrid. It is essentially a miniature version of the main grid. It can draw energy from both renewable and non-renewable sources [2]. For microgrids to operate efficiently, the energy supplied from the energy sources must be properly managed by an EMS. This LIA intelligently monitors the available energy sources and smartly delivers it to the electrical load categories that should be supplied, while they load shed the other categories in order to achieve the best energy management scheme based on the available resources. The LIA major goal is to supply a reliable and steady power within the SPGS sub-grid at the cheapest possible rate. The fuzzy rules are employed to decide when to engage the different sources available to the MG, and how long they will run in order to achieve the most economic viable energy management. The LIA is in charge of energy management and the general controls within the SPGS sub-grid. The fuzzy algorithm or algorithms called up each time depends on the state of the energy inputs to sub-grid. These energy inputs to the MG, include, utility grid, solar-PV system and diesel generators, however, the primary energy

source to this sub-grid is the renewable PV-solar energy source. The energy management system runs with an algorithm that ensures the maximum power availability within the MG at the minimum running cost.

According to [3], microgrid technology encourages Distributed Generation (DG). Distributed generation as contrast to bulk generation uses several renewable energy resources available to generate electricity at distributed locations. The locations can be supplied by majorly the energy generated in their location instead of totally relying on the National utility grid. More so, DG drastically reduces the pressure on the aging transmission grid infrastructure, which is one of the challenges the power vendors are currently facing. Several renewable energy sources can be harnessed to supply a MG. The renewable energy sources used should be determined by the ones readily available at the location of the MG. Solar energy is readily available at Nnamdi Azikiwe University Awka campus and was used for the SPGS sub-grid.

2. Review of Related Literature

2.1 Fuzzy Logic

Fuzzy logic is a convenient way to map an input space to an output space. Mapping input to output is the starting point for everything [4]. Though fuzzy logic maps inputs to outputs, it works with several simple fuzzy rules provided to take several complex decisions as it gives its output. Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multi-valued logic. Unlike discrete logic where there are discrete and précised points (that is either 1 or 0, HIGH or LOW), fuzzy logic gives output based on degree of membership. For example instead of just having HIGH or LOW, it will have VERY HIGH, HIGH, LOW and VERY LOW states, this corresponds to the range of possible points between 0 and 1. In a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with un-sharp boundaries in which membership is a matter of degree [5]. (Albertos and Antonio, 1998). Even in its more narrow definition, fuzzy logic differs both in concept and substance from traditional multi-valued logical systems. In recent years, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection[6].

2.1.1 Fuzzy Logic Tool Box in MatLab

Fuzzy Logic Toolbox provides MatLab functions, applications, and a Simulink block for analyzing, designing, and simulating systems based on fuzzy logic [7] and [8]. The product guides on the steps of designing Fuzzy Inference Systems (FIS). Functions are provided for many common methods, including fuzzy clustering and adaptive neuro-fuzzy learning. The toolbox lets you model complex system behaviours using simple logic rules, and then implements these rules in a fuzzy inference system [8]. (MathWorks,

2018). You can use it as a stand-alone fuzzy inference engine. Alternatively, you can use fuzzy inference blocks in Simulink and simulate the fuzzy systems within a comprehensive model of the entire dynamic system.

The key features of MatLab in the fuzzy logic tool box are as given below:

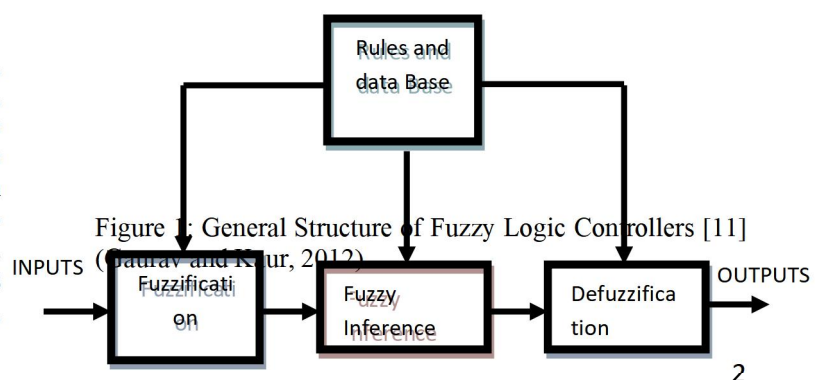
- Fuzzy Logic Design application for building fuzzy inference systems (FIS) and viewing and analyzing results
- Membership functions for creating fuzzy inference systems.
- Support for AND, OR, and NOT logic in user-defined rules.
- Standard Mamdani and Sugeno-type fuzzy inference systems.
- Automated membership function shaping through neuro adaptive and fuzzy clustering learning techniques.
- Ability to embed a fuzzy inference system in a Simulink model.
- Ability to generate embeddable C-language code or stand-alone executable fuzzy inference engines.

Another basic concept in Fuzzy Logic, which plays a central role in most of its applications, is that of a fuzzy if-then rule or, simply, fuzzy rule [9]. Although rule-based systems have a long history of use in Artificial Intelligence (AI), what is missing in such systems is a mechanism for dealing with fuzzy consequents and fuzzy antecedents [9]. In fuzzy logic, this mechanism is provided by the calculus of fuzzy rules. The calculus of fuzzy rules serves as a basis for what might be called the Fuzzy Dependency and Command Language (FDCL). Although FDCL is not used explicitly in the toolbox, it is effectively one of its principal constituents.

In most of the applications of fuzzy logic, a fuzzy logic solution is, in reality, a translation of a human solution into FDCL [10].

2.1.2 Fuzzy Logic Controllers

Fuzzy logic controllers in Simulink are used to implement, simulate and obtain results from fuzzy logic models. Using these controllers, one can view, analyse and make deductions on a simulation model. Figure 2.1 shows a generic structure of fuzzy logic controllers[11].



In figure 1, the fuzzification is the process of arranging the inputs with reference to the rules provided. The fuzzy inference block makes inference based on the provided rules, while the outputs are released by the process of defuzzification [12]. Thus the inputs are mapped to the outputs based on the fuzzy rules provided.

The advantages of modelling complex systems with fuzzy logic inference system (FIS) cannot be overemphasized. According to [13], [14] there are list of general observations about fuzzy logic that makes it an excellent modelling approach for very complex non-precision systems:

- Fuzzy logic is conceptually easy to understand.

The mathematical concepts behind fuzzy reasoning are very simple. Fuzzy logic is a more intuitive approach without the far-reaching complexity.

- Fuzzy logic is flexible. With any given system, it is easy to layer on more functionality without starting again from scratch.

- Fuzzy logic is tolerant of imprecise data. Everything is imprecise if you look closely enough, but more than that, most things are imprecise even on careful inspection. Fuzzy reasoning builds this understanding into the process rather than tacking it onto the end.

- Fuzzy logic can model non-linear functions of arbitrary complexity. You can create a fuzzy system to match any set of input-output data. This process is made particularly easy by adaptive techniques like Adaptive Neuro-Fuzzy Inference Systems (ANFIS), which are available in Fuzzy Logic Toolbox software.

- Fuzzy logic can be built on top of the experience of experts. In direct contrast to neural networks, which take training data and generate opaque, impenetrable models, fuzzy logic lets you rely on the experience of people who already understand your system.

- Fuzzy logic can be blended with conventional control techniques. Fuzzy systems do not necessarily replace conventional control methods. In many cases fuzzy systems augment them and simplify their implementation.

- Fuzzy logic is based on natural language. The basis for fuzzy logic is the basis for human communication. This observation underpins many of the other statements about fuzzy logic. Because fuzzy logic is built on the structures of qualitative description used in everyday language, fuzzy logic is easy to use. The last statement is perhaps the most important one and deserves more discussion. Natural language, which is used by ordinary people on a daily basis, has been shaped by thousands of years of human history to be convenient and efficient. Sentences written in ordinary language represent a triumph of efficient communication.

The above advantages make fuzzy logic excellent for energy management modelling of hybrid microgrids.

2.2 Fuzzy Logic Applications in Microgrid

According to [15], fuzzy logic technique enables the implementation of very complex control algorithm by using

very simple rule sets. The authors of [16], presented the design of a low complexity energy management system using Fuzzy logic Controller of only 25-rules for a residential grid connected microgrid including renewable Energy sources and storage capability. The EMS assumes that neither the renewable generation nor the load demand is controllable, hence the reason for employing fuzzy logic technique. The main goal of the design is to minimize the microgrid power profile fluctuations while keeping the battery State of Charge (SoC) within specified limits. Instead of using forecasting-based methods, this approach uses both the microgrid energy rate-of-change and the battery SoC to increase, decrease or maintain the power delivered/absorbed by the mains. Hence the EMS increases its consumption from the mains if the battery SoC is reducing, so as to allow the battery time to recharge, while it reduces its consumption from the mains when the battery SoC is increasing. The fuzzy controller ensures that there is a balance between the battery SoC, the renewable resources and the mains supply. The controller design parameters (membership functions and rule-base) were adjusted to optimize a pre-defined set of quality criteria of the microgrid behaviour. A comparison with other EMS designs seeking the same goal was presented at simulation level, whereas the features of this design were experimentally tested on a real residential microgrid implemented at the Public University of Navarre [16]. This work is closely related to the EMS, for SCHMG, however, the emphasis of the model was only on the battery State of Charge (SoC), whereas the EMS for SCHMG (LIA), took cognisance of SoC, public utility grid status and diesel generator status, it was also able to trigger intelligent load shedding when the need arises. Therefore, the EMS for the SCHMG model will definitely deliver a more steady and reliable power supply to its loads at the minimal cost.

Furthermore, [17] designed an Energy Management System for hybrid microgrid consisting of PV generation, Battery Energy Storage System (BESS) and Wind Energy Conversion System (WECS) using fuzzy logic control. The battery acted as a storage system, and the Energy Back-up (EB) system acted as a stand-by source, this source was committed during the power failure condition. The Energy Management System incorporated the fuzzy logic control, which was used to achieve the optimization and distributed energy generation. The main operation of this Energy Management System was that of committing the energy sources, and battery management. In the case of the battery management, the fuzzy logic algorithm controlled the State of Charge (SoC) parameters of the battery. In this work, an energy management system was modelled using fuzzy logic algorithm; however, it was more concerned about just the battery State of Charge (SoC), which is just one of the parameters being monitored in the EMS for the SCHMG. The EMS for the SCHMG checks the batteries SoC, the utility grid status, the diesel generator status and the auxiliary power status and takes specific decisions based on their states.

The authors of [18] a fuzzy logic controller that efficiently managed loads in a grid operated microgrid. This energy managements system co-ordinated the flow energy from inputs of the microgrid, which included the PV system with Maximum Power Point Tracking (MPPT) controller, the Battery Energy Storage System (BESS) with bulk converter and utility grid, to the critical and non-critical loads. The fuzzy logic based energy management system takes decisions based on the available input source and their status. The loads supplied, depended on the status of the input power sources being used. Here again, fuzzy logic energy management algorithm was focused on the flow of energy from the utility grid, rather that managing the entire energy resource available to the microgrid.

3. Methodology.

3.1 Mathematical Models for the SPGS Sub-grid

The estimated electrical loads for the SPGS sub-grid are broadly divided into two major types namely;

Daytime electrical Loads (P_d) in kW and Night-time electrical Loads (P_n) in kW.

Daytime electrical Loads are the electrical loads that are used during the day only, while the night-time electrical loads are loads used during the nights only.

Where (P_d) is the summation of the wattages of appliances and any other form of electrical loads in kW used during the day, between 8.00am to 7.00pm.

(P_n) is the summation of the wattages of electrical loads in kW used in the night between, 7pm to 8am.

Therefore

$$P_d = \sum_1^m (P_{dm}) \tag{1}$$

$$P_d = P_{d1} + P_{d2} + P_{d3} + \dots + P_{dm} \tag{2}$$

Also for the electrical loads used in the night (P_n)

$$P_n = \sum_1^m (P_{nm}) \tag{3}$$

$$P_n = P_{n1} + P_{n2} + P_{n3} + \dots + P_{nm} \tag{4}$$

The electrical loads in the SPGS sub-grid are categorised into three categories, namely; High priority loads (hpls), priority loads (pls) and less priority loads (lpls) in their order of priority to the sub-grid

All the night electrical loads (P_n) are majorly security lighting systems and other security gadgets; hence they are all high priority loads (**hpls**).

3.1.1 Mathematical Representation of the Load categorisation of the SPGS Sub-grid

From the above categorisation, the total wattage of the electrical loads used during the day (P_d) for each of the sub-grid can be represented mathematically as shown in (5).

$$P_d = P_{d(hpl)} + P_{d(pl)} + P_{d(lpl)} \tag{5}$$

For night electrical loads, since all they are all high priority loads (hpls)

$$P_n = P_{n(hpl)} \tag{6}$$

There the total load demand for the sub-grid is mathematically given by

$$P_{total} = P_d + P_n \tag{7}$$

3.1.2 Mathematical formation for the Total Energy Demand (TE_{dem}) at the SPGS sub-Grid

The total energy demand (TE_{dem}) is the total energy the SPGS sub-grids requires to supply its electrical load categories for the designated hours of operation.

Therefore,

$$TE_{dem} = E_{dem(day)} + E_{dem(night)} \tag{11}$$

$$TE_{dem} = (P_n \times T_{night}) \text{ in kWh} + (P_d \times T_{day}) \text{ in kWh}$$

Representing TE_{dem} mathematically, the total energy consumption in a building with n numbers of electrical loads for a period of time T is given by (12)

$$TE_{dem} = \sum_1^n \int_0^T (IV \cos\theta) dt \tag{12}$$

Where

I = current drawn by the electrical loads per time (t).

V = Voltage across the electrical loads.

$\cos\theta$ = power factor of the electrical load.

The loads are further grouped into two types namely Resistive and Reactive loads.

For resistive loads, $\cos\theta = 1$ while for Reactive loads $\cos\theta \neq 1$

Therefore,

$$TE_{dem} = \sum_1^Q \int_0^T (IV \cos\theta) dt + \sum_1^P \int_0^T (IV) dt \tag{13}$$

Where P is the total number of resistive loads being considered and Q is the total number of reactive loads being considered.

Let the power drawn by the resistive loads for time t be P_r and that of the reactive loads be P_c

This implies that $P_r = IV$ while $P_c = IV \cos\theta$

Therefore

$$TE_{dem} = \sum_1^Q \int_0^T P_{cdt} + \sum_1^P \int_0^T Prdt$$

Expanding the expression above we get

$$TE_{dem} = P_{c1} \int_0^T dt + P_{c2} \int_0^T dt + \dots + P_{cQ} + \int_0^T dt + P_{r1} \int_0^T dt + P_{r2} \int_0^T dt + \dots + P_{rP} \int_0^T dt \tag{14}$$

(14) is the mathematical model for the total energy demand (TE_{dem}) of the SPGS sub-grid.

3.2 Model of the Localized Intelligent Agent (LIA)

The LIA is a multifunction intelligent Agent responsible for Energy management at the SPGS sub-grid. It was modelled using the fuzzy logic tool box in MatLab. Figure 2 shows the high level description of the LIA. It clearly portrays all the energy inputs to the sub-grid and shows the electrical load categories at the SPGS sub-grid. This model controls the energy scheduling among the available energy sources to the sub-grid and takes care of intelligent load shedding whenever there is a short fall in the solar plant energy generation. The SPGS microgrid is designed with solar energy as the primary source of power to the sub-grid. This implies that once the solar plant can supply at least the hpls, the sub-grid will thrive on solar energy.

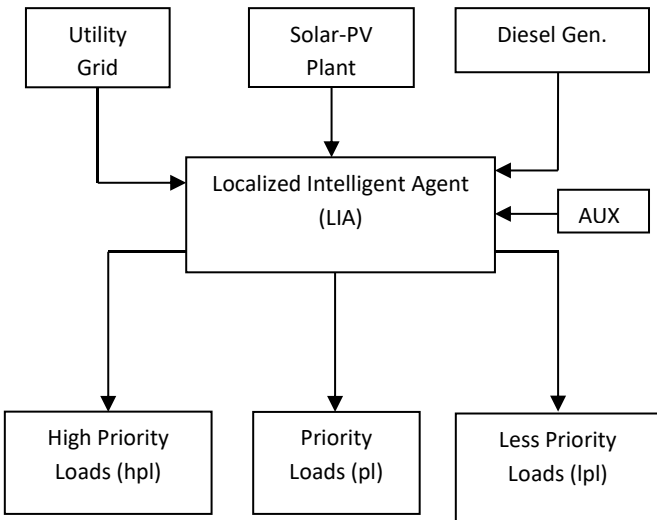
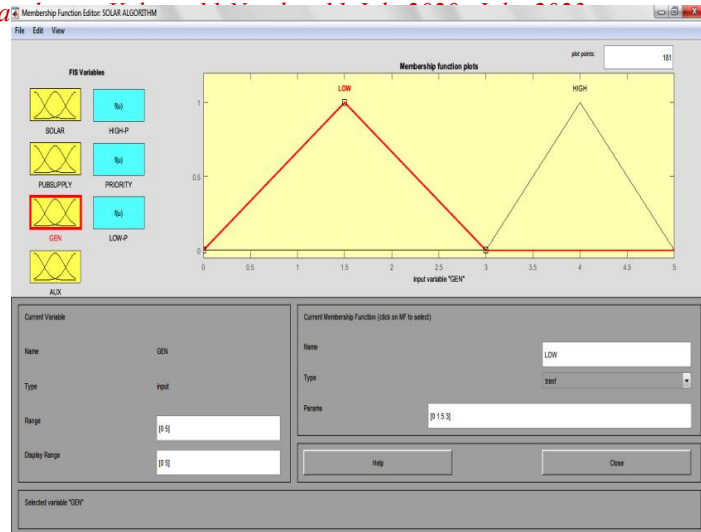


Figure 2: High Level Description Model of the Fuzzy-Logic EMS (LIA)

The LIA monitors the status of the different aspects of the sub-grid. It monitors the status of the solar plant which includes the solar-PV, the State of Charge (SoC) of the BESS, the status of the battery inverter; the status of utility grid and the diesel generators. At any point in time, the LIA manages the available energy within the sub-grid to ensure the delivery of a reliable, cost-effective and steady power supply to different electrical load categories within sub-grid. It is also responsible for triggering the intelligent load shedding protocol in case of energy shortfalls within the sub-grids. It can engage or disengage one or more of the energy sources in order to realize its set goals or objectives.

3.3 The Fuzzy Logic Model of the LIA



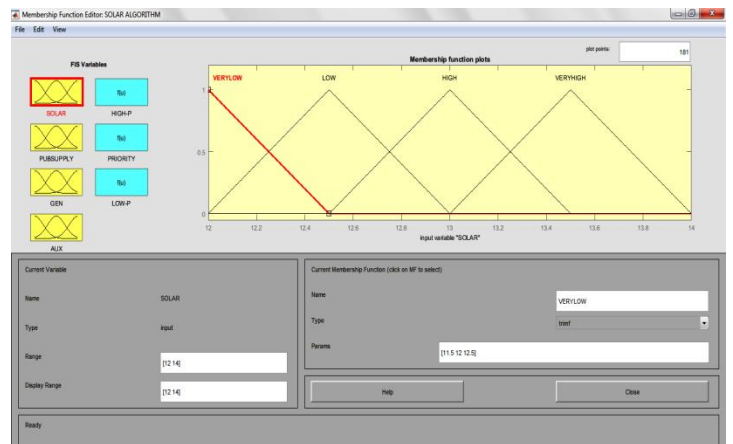
3.3.1 Fuzzification Process

The fuzzy logic modelling starts with the fuzzification of all the energy input sources to the sub-grid. Here the different fuzzy states of the different energy inputs available to the sub-grid were defined with respect to the fuzzy rules (algorithms), developed to map these inputs to their respective outputs (defuzzification). Figure 3 shows the fuzzification of the solar plant, based on the BESS State of Charge (SoC). Four major states or membership functions were clearly defined corresponding to the following fuzzy logic linguistic variables, VERYLOW (12.1V), LOW (12.5V), HIGH (13V) and VERYHIGH (13.5). The other three energy input sources to this sub-grid i.e, the utility grid (PUBSUPPLY), Diesel Generator (GEN), and auxiliary power from neighbouring sub-grids (AUX), are defined by only two fuzzy states or membership functions, corresponding to the fuzzy logic linguistic variables, LOW(1-1.5V) and HIGH(4.5-4.9V). This is because they are either available or not. Figure 4 shows the fuzzification of the diesel generator (GEN), which also applies to both AUX

Figure3: Fuzzification of the Solar input

Figure4: Fuzzification of the PUBSUPPLY energy input

3.3.2 Defuzzification Process

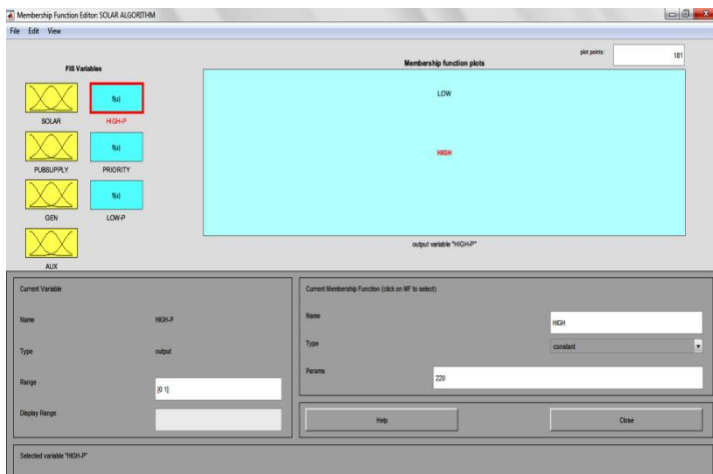


The defuzzification process entails the fuzzy inference releasing the designated outputs based on the provided fuzzy rules. In this case, each load category was supplied based on the states of the energy inputs and fuzzy rules provided. The outputs, the hpls, pls and the lpls were modelled with only two state or membership functions; HIGH or LOW, since they are either supplied or not supplied. Figure 6 shows the modelling of the defuzzification process for HIGHP load category, and this applies to the other two load categories also.

Figure6: The Defuzzification of High Priority Loads

The complete MatLab-fuzzy model of the LIA is shown in figure 7, and the fuzzy control algorithm or the fuzzy rules are shown in figure 8

Figure 7: The MatLab Fuzzy logic model of the LIA.



1. If (SOLAR is VERYHIGH) then (HIGH-P is HIGH) (PRIORITY is HIGH) (LOW-P is HIGH)
2. If (SOLAR is HIGH) and (AUX is HIGH) then (HIGH-P is HIGH) (PRIORITY is HIGH) (LOW-P is HIGH)
3. If (SOLAR is VERYHIGH) and (PUBSUPPLY is HIGH) then (HIGH-P is HIGH) (PRIORITY is HIGH) (LOW-P is HIGH)
4. If (SOLAR is HIGH) and (PUBSUPPLY is LOW) and (AUX is LOW) then (HIGH-P is HIGH) (PRIORITY is HIGH) (LOW-P is LOW)
5. If (SOLAR is LOW) and (PUBSUPPLY is LOW) and (AUX is LOW) then (HIGH-P is HIGH) (PRIORITY is LOW) (LOW-P is LOW)
6. If (SOLAR is LOW) and (PUBSUPPLY is LOW) and (AUX is HIGH) then (HIGH-P is HIGH) (PRIORITY is LOW) (LOW-P is LOW)
7. If (SOLAR is LOW) and (PUBSUPPLY is HIGH) then (HIGH-P is HIGH) (PRIORITY is HIGH) (LOW-P is HIGH)
8. If (SOLAR is VERYLOW) and (PUBSUPPLY is LOW) and (GEN is LOW) and (AUX is HIGH) then (HIGH-P is HIGH) (PRIORITY is LOW) (LOW-P is LOW)
9. If (SOLAR is VERYLOW) and (PUBSUPPLY is LOW) and (GEN is HIGH) and (AUX is LOW) then (HIGH-P is HIGH) (PRIORITY is HIGH) (LOW-P is HIGH)
10. If (SOLAR is VERYLOW) and (PUBSUPPLY is LOW) and (GEN is LOW) and (AUX is LOW) then (HIGH-P is LOW) (PRIORITY is LOW) (LOW-P is LOW)
11. If (SOLAR is VERYLOW) and (PUBSUPPLY is HIGH) and (GEN is LOW) and (AUX is LOW) then (HIGH-P is HIGH) (PRIORITY is HIGH) (LOW-P is HIGH).

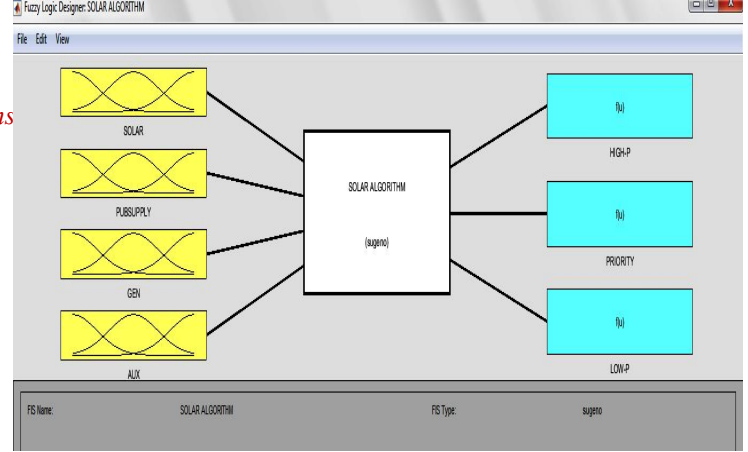


Figure 8: Fuzzy logic rules for the LIA control

3.3.3 Fuzzy logic Model Simulation in Simulink

The MatLab fuzzy logic model called SOLAR_ALGORITHM.fis was then downloaded into a fuzzy logic controller with rule view in Simulink where it was tested using test signals and the results of different test scenarios were recorded. Figure 9 shows the Simulink model arrangement for testing the modelled LIA.

The Simulink model comprises of four constant blocks for input purposes, a multiplexer block, a fuzzy logic controller with rule view a demultiplexer block and three display blocks to display the outputs.

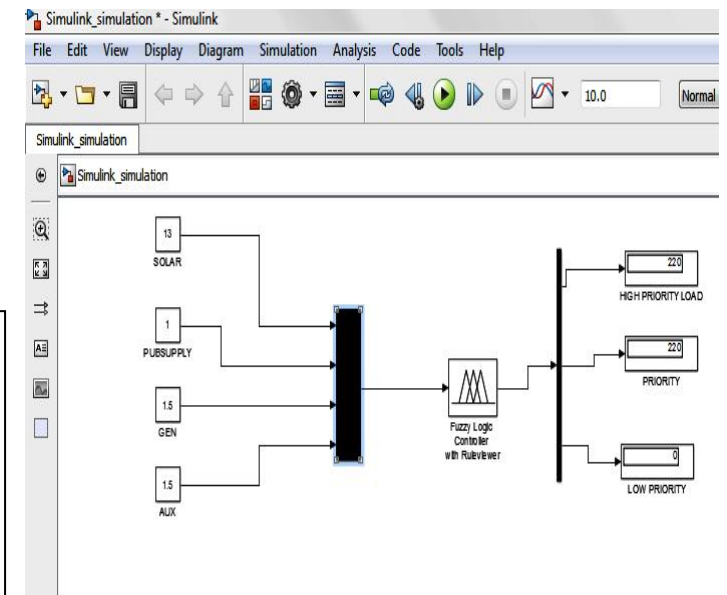


Figure9: Simulink Model of the LIA

4. RESULTS AND DISCUSSIONS

4.1 Test Scenario for the LIA

Ten scenarios have been used to test the modelled energy management system and the results of the system response are recorded and compared with expected results. Table 1 summarizes the test results and their comparison with expected result. The ten scenarios are;

- Scenario 1: Solar is VERY HIGH with all other inputs HIGH
- Scenario 2: Solar is VERYLOW with all the other inputs LOW
- Scenario 3: Solar is VERY HIGH with all other inputs LOW
- Scenario 4: Solar is VERY LOW,PUBSUPPLY HIGH with all other inputs LOW
- Scenario 5: Solar is VERY LOW, AUX. HIGH with all other inputs LOW
- Scenario 6: Solar is VERY LOW, GEN. HIGH with all other inputs LOW
- Scenario 7: Solar is LOW with all other inputs LOW
- Scenario 8: Solar is LOW, AUX. HIGH, with all other inputs LOW
- Scenario 9: Solar is HIGH with all other inputs LOW
- Scenario 10: Solar is HIGH, AUX. HIGH with all other inputs LOW

4.2 Presentation of result for some Test scenarios

All the results of the LIA test are summarized in table1; however, the results for scenariol is presented in figure 10 and 11

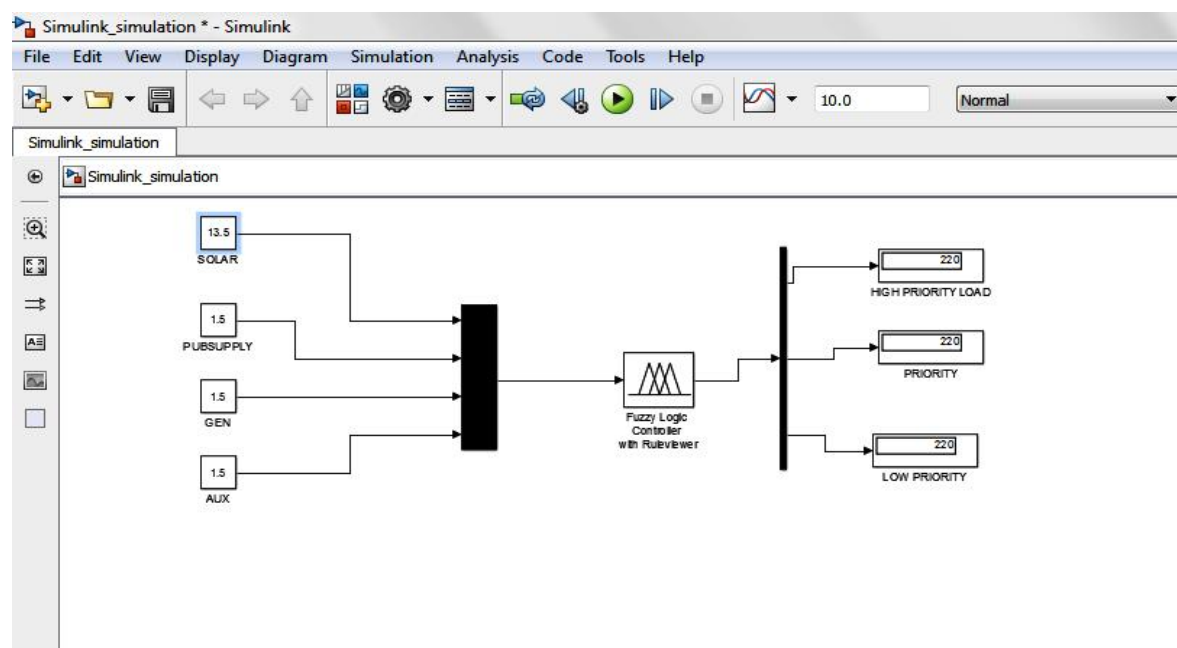


Figure 10: Simulation for Scenario 1.

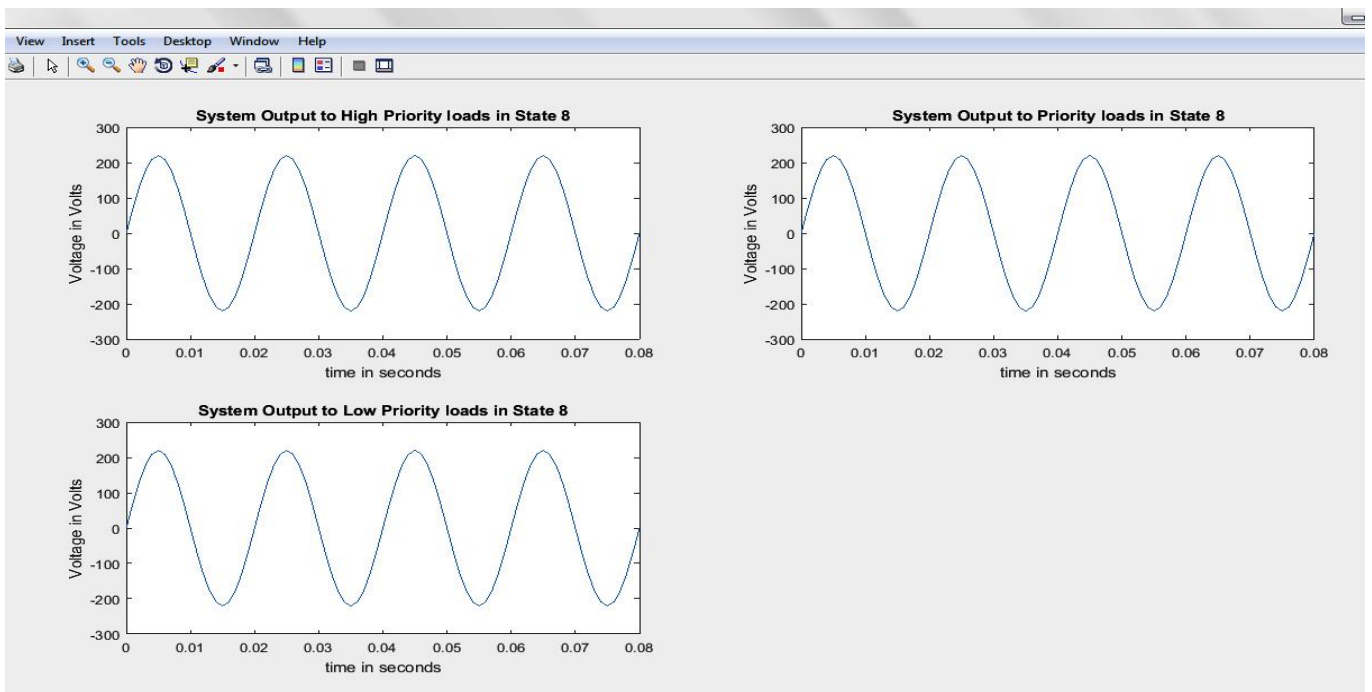


Figure 11: Graphical view for Scenario1

Table1 : Summary of Test Results

S/N	Test Case Scenarios	Expected System Outputs	Actual System Outputs
1	Solar is VERY HIGH with all other inputs HIGH	All the load categories supplied. The power source to the microgrid taking from Solar Plant	All the load categories were supplied as shown in figure 10
2	Solar is VERYLOW with all other inputs LOW	No load should be supplied at all.	There was no output to the all the load categories.
3	Solar is VERYHIGH with all other inputs LOW	All the load categories should be supplied.	All the load categories were supplied.
4	Solar is VERYLOW, PUBSUPPLY HIGH with all other inputs LOW	All to load categories should be supplied from the utility grid	All the load categories were supplied.
5	Solar is VERY LOW, AUX. HIGH with all other inputs LOW	Only the high priority loads should be supplied.	Only the high priority loads were supplied.
6	Solar is VERY LOW, GEN. HIGH with all other inputs LOW	All the load categories should be supplied from the diesel generator.	All the load categories were supplied.
7	Solar is LOW with all other inputs LOW	Only the high priority loads should be supplied.	Only the high priority loads were supplied.
8	Solar is LOW, AUX. HIGH, with all other inputs LOW	Only the high priority loads are supplied.	Only the high priority loads were supplied.
9	Solar is HIGH with all other inputs LOW	The high priority and the priority loads are supplied	High priority and priority loads were supplied.
10	Solar is HIGH, AUX. HIGH with all other inputs LOW	The high priority and the priority loads should be supplied.	High priority and the priority loads are supplied.

5. CONCLUSION

The LIA model chooses the cheapest possible option for the delivery of a reliable, cost effective and steady electricity power supply to the SPGS sub-grid. This model being a multi-function intelligent Agent serves the purpose of proper energy scheduling and load shedding whenever the need arises. All the load categories are supplied once either GEN input or the PUBSUPPLY input or both are available and when the SOLAR input is at VERYHIGH state. However, the primary supply to this sub-grid is the renewable source of Solar-PV.

REFERENCES

- [1] Gibin, M. P., Twinkle, T., Juliya, S., Miranda, T., & Gopakumar, P. (2016). Hybrid Ring Micro Grid with co-ordinated Energy Management Scheme. *Science Direct, Elsevier, Procedia Technology* 25 , 793-800.
- [2] Robert, L., Abaas, A., Chris, M., John, S., Jeff, D., Ross, G., et al. (2002). *Integration of Distributed Energy Sources, White Paper on the CERTS Micro grid Concept*. California: Consortium for Electric Reliability Technology Solutions.
- [3] Longe, O. M., Rao, N. D., Omowole, F., Oluwalami, A. S., & Oni, O. T. (2017). A Case Study on Off-grid Micro grid for Universal Electricity Access in the Eastern Cape of South Africa. *International Journal of Energy Engineering* , 55-63.
- [4] Al-Odienat, A. I., & Al-Lawama, A. A. (2008). The Advantages of PID Fuzzy Controllers Over The Conventional Types. *American Journal of Applied Science*, V (6), 653 -658.
- [5] Albertos, P., & Antonio, S. (1998). *Fuzzy Logic Controllers, Advantages and Drawbacks*. Valencia: Universidad politecnica de Valencia.
- [6] Gupta, P. (2017). Applications of Fuzzy Logic in Daily life. *International Journal of Advanced Research in Computer Science*, VIII (5).
- [7] Costa, B. S., Clauber, G. B., & Luiz, A. H. (2012). A multistage fuzzy controller: Toolbox for industrial applications. *IEEE International Conference on Industrial Technology*, (pp. 1142-1147).
- [8] MathWorks. (2018). *MATHWORKS*. Retrieved April 18, 2019, from MATHWORKS: <https://uk.mathworks.com/help/fuzzy/release-notes.html>
- [9] Chevrie, F., & Guely, F. (1998). *Fuzzy Logic*. Rueil-Malmaison: Groupe Schneider.
- [10] Umarikar, A. (2003). *Fuzzy Logic and brief overview of its applications*. Suecia: University Västerås.
- [11] Gaurav, A. K., & Kaur, A. (2012). Comparison between conventional PID and fuzzy logic controller for liquid flow control: Performance evaluation of fuzzy logic and PID controller by using MATLAB/Simulink.
- [12] Naderii, A., Ghasemzadehii, H., Pourazar, A., & Aliasgharyii, M. (2009). Design of a Fuzzy Controller Chip with New Structure, Supporting Rational-Powered Membership Functions. *AUT Journal of Electrical Engineering*, 41 (2), 65-71.
- [13] Sugeno, M., & Yasukawa, T. (1993). A fuzzy-logic-based approach to qualitative modeling. *IEEE Transactions on fuzzy systems*, I (1), 7.
- [14] Farouk, N., & Sheng, L. (2012). Design and Implementation of a Fuzzy Logic Controller for Synchronous Generator. *Research Journal of Applied Sciences, Engineering and Technology*, IV (20), 4126-4131.
- [15] Bih, J. (2006). Paradigm shift-an introduction to fuzzy logic. *IEEE potentials* , 6-21.
- [16] Arcos-Aviles, D., Pascual, J., Marroyo, L., Sanchis, P., & Guinjoan, F. (2018). Fuzzy logic-based energy management system design for residential grid-connected microgrids. *IEEE Transactions on Smart Grid*, IX (2), 530-543.
- [17] Ruban, A. A., Rajasekaran, G. M., & Rajeswari, N. (2015). Implementation of energy management system to PV-Wind hybrid power generation system for DC microgrid applications. *Int Res J Eng Technol*, II (8), 204-210.
- [18] Garrab, A., Bouallegue, A., & Bouallegue, R. (2017). An agent based fuzzy control for smart home energy management in smart grid environment. *International Journal of renewable energy research*, VII (2), 599-612.