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An Energy Management System for Campus Hybrid Microgrid Using a Multifunction Intelligent Agent (A case of SPGS Nnamdi Azikiwe University Awka Campus)

Ajuzie U.C., Azubogu A.C.O, Inyiama H.C

Abstract*-This work presents an energy management system (EMS) for Campus Hybrid Microgrid (CHMG) using a multifunction intelligent Agent for the School of Postgraduate Studies (SPGS), in Nnamdi Azikiwe University Awka Campus Anambra State Nigeria. Electrical load estimation carried out for the SPGS sub-grid, gives the specifications and the system requirements for the deployment solar-diesel hybrid microgrid for the sub-grid. Three major electric power sources are available to the sub-grid namely; solar photovoltaic (PV), diesel generator and utility grid. The intelligent agent called Localized intelligent Agent (LIA) performs the functions of switching over from one energy source to the other and intelligent load shedding among categorised electrical loads, which are; the high priority loads(hpls), priority loads (pls) and the less priority loads(lpls), based on the developed energy management algorithm. The main goal of this multifunction intelligent agent is to monitor and manage energy within the sub-grid, in order to ensure the delivery of reliable, cost–effective and steady power supply to sub-grid. Thus improving the quality of electricity supply to the SPGS sub-grid, while reducing the Cost of Energy (CoE) provision to the barest minimum.*

Key Words: *Campus, Cost of Energy(CoE), high priority loads(hpls), Hybrid, intelligent Agent , less priority loads (lpls), Microgrid(MG), multifunction, priority loads(pls), solar PV, SPGS sub-grid.*

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1. INTRODUCTION

The energy management system (EMS) of any microgrid (MG) is a very important and major part of every hybrid microgrid, which takes care of energy management within the microgrid. It is in charge of harnessing all the available energy sources to the microgrid, making intelligent decision based on the available energy sources and distributing the energy to the loads intelligently. For the purpose of this study, a case of EMS for campus solar-diesel hybrid microgrid, with utility power supply for SPGS sub-grid at Nnamdi Azikiwe University Awka Campus was studied. The EMS deployed is a multi-function intelligent agent termed Localized Intelligent Agent (LIA). The MG under study is the SPGS sub-grid.

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. The LIA intelligently monitors the available energy sources and decides the electrical loads that should be supplied and the ones that should be load-shaded in order to achieve the best management scheme based on the available resources. The LIA targets to supply reliable and steady power within the MG at the cheapest possible rate. It also decides 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 general control and energy management within the SPGS sub-grid. It manages the inputs to the MG, which come from the utility grid, solar-PV system and diesel generators. The LIA also controls the supply of power to the different categories of the electrical loads within the MG. The energy management system runs with an algorithm that

- *Ajuzie U.C is currently pursuing PhD degree program in Electronic and Computer engineering in Nnamdi Azikiwe University, Awka Anambra Nigeria.PH: +2348034119141 E-mail: ajuziasoftbiz@gmail.com*
- *Azubogu A.C.O is a Professor in the Department of Electronic and Computer engineering in Nnamdi Azikiwe University Awka Anambra State Nigeria, PH-+2348059626829. E-mail: ac.azubogu@unizik.edu.ng*
- Inyiama H.C *is a Professor in the Department of Electronic and Computer engineering in Nnamdi Azikiwe University Awka Anambra State Nigeria E-Mail: hc.inyiama@unizik.edu.ng*

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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 grid. More so, DG drastically reduces the pressure on the aging transmission grid infrastructure, which is one of the challenges the public 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 and that can easily be harnessed at the MG location. Solar energy is readily available at Nnamdi Azikiwe University Awka campus and was used for the SPGS sub-grid.

2 LITERATURE REVIEW

2.1 Intelligent Agents

According to [4], an agent is anything that can be viewed as perceiving its environment through sensors and acting upon its environment through actuators. Also, [5] pointed out that agents perceives their environments through sensor, and then achieve a preset goal by acting on their environment through actuators. A very good example of an agent is the human agent, that perceives their environment through their eyes, ears, and other sense organs (representing sensors), and achieve their set goals using their hands, legs, mouth, and other body parts, which represents actuators. Agents can also be seen as a mapping between percept sequences and actions [6]. This simply means that agents can receive inputs (perceive) through their sensors, take certain control decision based on their set goals, and deliver the expected outputs through their actuators or effectors.

The authors of [6] identifies four classes of intelligent agents namely; simple reflex agents, goal-based agents, utility-based agents and learning agents. From the classification above, the intelligent agent class that satisfies the developed LIA is the utility- based agent, however, it possesses some attributes of the reflex and the goal-based agent. The works of [7] introduced multi-agent modelling for games. In their opinion, it is easier to break down a very complex theory into smaller units that can be managed by multiple intelligent agents.
In the resulting system, each agent will be dedicated to execute a specific task and by this method the complexity of modelling one complex system will be reduced to the modelling many simple agents.
In addition, [8] introduced artificial agents, in their view Agents are advanced tools people use to achieve different goals and to solve various problems. The main difference between ordinary tools and agents is that agents can function more or less independently from those who delegated agency to the agents. For a long time people used only other people and sometimes animals as their agents. Developments in information processing technology, computers and their networks, have made it possible to build and use artificial agents. Intelligent agents form a basis for many kinds of advanced software systems that incorporate varying methodologies, diverse sources of domain knowledge, and a variety of data types.

The intelligent agent (IA) approach has been applied extensively in business applications, and more recently in medical decision support systems [9] and [10]. Apart from the noted applications, intelligent agents can be applied in the EMSs for MGs. In this unique application, their set goal will be to manage the available energy inputs to the MG, and deliver a steady supply of power at the cheapest possible running cost. The author of [11] viewed intelligent agents as a machine designed to perform work helpful to it owners. Agents can perform their dedicated goals automatically and intelligently without any human assistance or supervision. Intelligent agents seek to achieve what humans can do exactly the way they would have done them. An intelligent agent can be a hardware agent or a software agent.

Generally, an agent needs a hardware in which it is embodied, and software to enable it to respond appropriately to the environment which it lives in. In addition, [12] introduced the possibilities of multi-agent system application for the modelling and intelligent control in the case of coarse ceramics burning process. It consists of technological description of this process, its decomposition into agents and macro-model of the decision system. This application is closely related to the EMS in view because the LIA will also take care of the intelligent control and energy managements of the MG. It is meant to take appropriate decisions based on the received inputs ensuring the proper management of the available energy sources, in order to deliver a steady, cost effective and reliable electric power supply to the MG.

2.2 Intelligent Agents in Electric Power Control Application

The application of intelligent agents in the control of electricity is growing drastically. This is because before now most controls in the power sector were manually

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done by humans. Figure 1 shows the manual data acquisition and control of electric feeders at a substation in Awka south local government Area of Anambra State.

Figure 1: Manual feeder control and data acquisition at a substation by a Power Utility Staff.

This level of intelligence and control can only be mimicked by intelligent agents. For example, the scenario in figure 1 can comfortably be handled by an intelligent agent, which will monitor the power lines, log data acquired and make decision on when to handle feeder control. The authors in [13] and [14] presented the requirement analysis for autonomous systems and intelligent agents in future Danish Electric power system. They opined that an intelligent agent is an encapsulated computer system that is situated in some environment and can act flexibly and autonomously in that environment to meet its designed objectives. Intelligent Agents are autonomous and can exercise control over their state and behaviour; they are proactive and can take initiatives by themselves rather than passively responding to changes in their environment. Just like humans, intelligent agents are social and can communicate in high level dialogues.

Adding, intelligent agents can be seen as autonomous systems which can react intelligently and flexibly on changing operating conditions and demands from the surrounding processes [15]. Such intelligent and autonomous systems provide capabilities like decomposition, reasoning, dynamic, flexibility (dynamic reconfiguration) and cooperation modelling. These qualities make intelligent agents a very viable option in innovative control architectures in electric power systems [16]. More so, intelligent agents are considered appropriate for applications that are modular, decentralized, changeable, and complex [17]. The requirements for electric power control are completely met by the abilities of intelligent agents and so they are viable application that can help translate manual electric power controls to intelligent automatic controls. In addition, [18] presented agent concept for intelligent distributed coordination in the Electric power grid. They opined that intelligent agents and multi-agent systems promise to take information management for real-time control of the power grid to a new level. In their report, concept for intelligent agents mediating and coordinating communications between Control Areas and Security Coordinators for real-time control of the power grid was presented. The authors of [19] presented practical applications of multi-agent system in electric power systems. They pointed out that to translate the current status of energy networks from passive to active system requires the embedding of intelligence within the network, and one of the most suitable approaches to achieve this is by the use of intelligent agent concept.

According to [20], an intelligent agent is one that is capable of flexible autonomous action in order to meet its design objectives. The LIA designed should meet the three basic criteria;

- Reactivity: The LIAs should be able to perceive their environment via dedicated sensors, and respond in a timely fashion to changes that occur in it in order to satisfy their design objectives;
- Pro-activeness: The LIAs should able to exhibit goal-directed behaviour by taking the initiative in order to satisfy their design objectives;
- Social ability: The LIAs should be able to interact with other LIAs (and possibly humans) in order to satisfy their design objectives [21].

The intelligent agent concept will enable the resulting LIA to be flexible enough to take appropriate control decision without human interference.

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;
Day electrical Loads **(P_d)** in kW and Night electrical Loads **(P_n)** in kW.
Day electrical Loads are the electrical loads that are used during the day only, while the night 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.

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Therefore

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

$$P_d = P_{d1} + P_{d2} + P_{d3} + \ldots + P_{dm} \quad (2)$$

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

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

$$P_n = P_{n1} + P_{n2} + P_{n3} + \ldots + P_{nm} \quad (4)$$

The day electrical loads at the SPGS sub-grids are further categorized into three major categories, namely high priority (hpl), priority loads (pl) and less priority loads (lpl), in their order of priority.

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 High Priority Loads

High Priority loads **(P_d) hpl** are the electrical loads that are critical and must be supplied with power whenever they need it, no matter the status of the microgrid. The appliances that fall within this category are internet modems, computers, printers, photocopiers, public address system, water pumping machines, office lightings, ceiling fans. Also all night loads which include security lighting system and other security gadgets are categorized under **hpls.** The **hpls** were selected based on their level of importance.

3.1.2 Priority Loads

Priority loads **(P_d) pl** are loads that should be supplied with power once the **hpls** have enough and the available power within the sub-grid is enough to supply them. The electrical load categorized as priority loads include air conditioners and water dispensers.

3.1.3 Less Priority Loads

Less Priority loads **(P_d) lpl** are loads that are supplied when the power generated by sub-grid is enough to supply the entire electrical loads within the sub-grid. Electrical loads categorized under the category are TVs, refrigerators, deep freezers. This electrical load categorization was done to enable intelligent load shedding once there is a short fall in generated energy within the sub-grid.

The categorizations of the loads are subject to amendment depending on priority of each sub-grid.

3.1.4 Mathematical Representation of the Load categorisation of the Sub-grids

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).

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

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

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

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

$$P_{total} = P_d + P_n \quad (7)$$

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

The total energy demand (TE_{dem}) is the total energy each of the sub-grids within the microgrid requires to supply its electrical loads for the desired hours of operation.

Therefore,

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

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

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 [24];

$$TE_{dem} = \sum_1^n \int_0^T (IVCos\theta)dt \quad (12)$$

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,

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

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 $P_c = IVCos\theta$

Therefore

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

Expanding the expression above we get

$$TE_{dem} = P_{c1} \int_0^T dt + P_{c2} \int_0^T dt + - - - + P_{cQ} + \int_0^T dt + P_{r1} \int_0^T dt + P_{r2} \int_0^T dt + - - - + P_{rP} \int_0^T dt \quad (14)$$

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

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3.2 Brief Description of the SPGS sub-grid.

The SPGS sub-grid refers to the electrical supply network to the School of Postgraduate Studies in Nnamdi Azikiwe University Awka campus. From the electrical load estimation done at the SPGS,

$P_{total} = P_d + P_n = 93.425kW$

$P_d \approx 87.925kW$, While $P_n \approx 5.5kW$

It is obvious that more electrical loads are used during the day than at night. That is an advantage, since one of the major and cost efficient energy sources to the CHMG is the solar energy which is readily available during the day.

Mathematically,

$$P_d > P_n \quad (15)$$

Let energy Demand during the day be denoted by $E_{dem(day)}$, while the energy demand during the night is represented by $E_{dem(night)}$.

Assuming all the installed electrical loads are in use, then the energy demand in the night is giving by

$$E_{dem(night)} = P_n \times T_{night} \text{ in kWh} \quad (16)$$

But P_n = 5.5kW, while T_{night} = (7pm to 7am) = 12Hrs

Therefore

$E_{dem\ (night)}$ = 5.5kW x 12hrs = 66kWh of Energy

Also

$$E_{dem\ (day)} = P_d \times T_{day} \text{ in kWh} \quad (17)$$

But Pd = 87.925kW, T_{day} = (8am to 5pm) = 9hrs

Assuming all electrical loads will be in use at the same time,

$E_{dem\ (day)}$ = 87.925kW x 9hrs = 791.325kWh of Energy

However, the assumption that all the loads will be used for the same duration is not obtainable in reality. In practice, the Energy demand will be variable depending on the loads that are being used at any giving time.

In summary, the solar plant for the SPGS sub-grid should be able to supply $E_{dem\ (day)}$ during the day and reserve (store up) $E_{dem\ (night)}$ for the night loads.

The design took into consideration of the average optimal sun hours, which is approximately 5 hours daily [23].

So the solar plant, which is made up of the solar-PV modules, Maximum Power Point Tracking(MPPT) charge controllers, Battery Energy Storage System(BESS) and Battery inverter for the sub-grid should be able to harvest **($E_{dem\ (day)}$ + $E_{dem\ (night)}$)** within 5hours.

These analyses enhanced the accuracy of the solar plant design decisions that was taken for the SPGS sub-grid.

$E_{dem\ (day)}$ = 712.35kWH of Energy

While **$E_{dem\ (night)}$** = 60kWH of Energy

3.3 Model of the Localized Intelligent Agent (LIA)

The LIA is a multifunction intelligent Agent responsible for Energy management at the SPGS sub-grid. It 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 show the high level description of the LIA model.

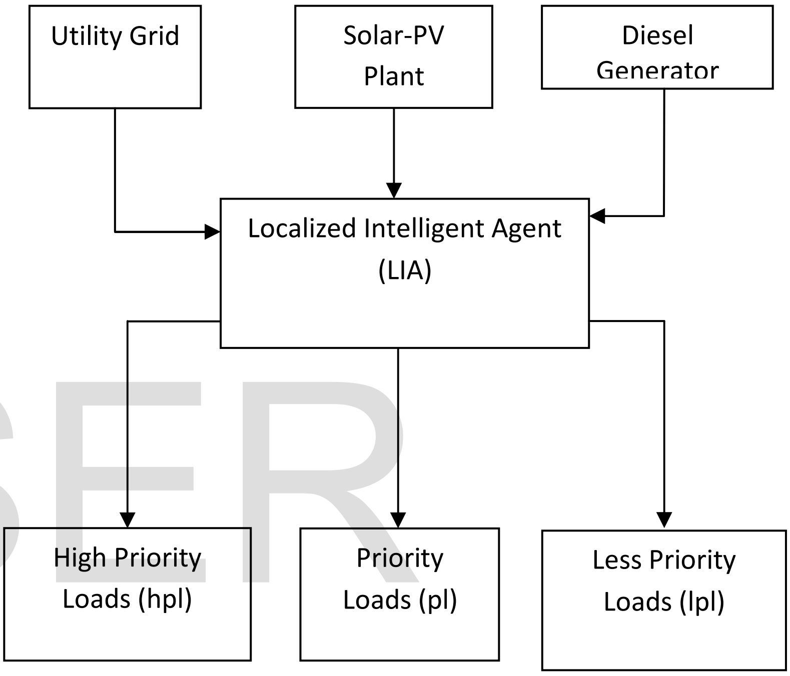

Figure 2: High Level Description Model of the LIA

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 it set goals or objectives.

3.3.1 Mathematical Model of the LIA

For the solar plant to sustainably supply all the electrical load categories within sub-grid, the energy available (**E_{avb}**) must be greater than the total energy demand of the sub-grid (**TE_{dem}**). The BESS is always engaged since the developed solar plant, runs on battery inverter (also

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called converters). However, during the day when solar energy is available, as the energy is being drawn from the BESS, part or all of the energy drawn will also be replaced by the solar-PV modules.

Mathematically,

Energy Available (**E_{avb}**) > Total Energy Demand (**TE_{dem}**)

That is

$$E_{avb} > TE_{dem} \quad (18)$$

But

$$TE_{dem} = E_{dem(hpl)} + E_{dem(pl)} + E_{dem(lpl)} \quad (19)$$

Where **$E_{dem\ (hpl)}$** = Energy demanded by High Priority Loads

$E_{dem\ (pl)}$ = Energy demanded by Priority Loads

$E_{dem(lpl)}$ = Energy demanded by Less Priority Loads

Since this solar plant is based on battery inverters, then

E_{avb} = Energy Stored in the battery bank (that is BESS) in kWh

Let the installed battery capacity be **B_{inst}** in kWh

The available battery capacity for use (Spotnitz, 2003)

$$B_{avb} = B_{inst} \times \text{DoD (Depth of Discharge)} \quad (20)$$

DoD is the maximum discharge depth allowed for the BESS expressed in percentage (Spotnitz, 2003).

But

$$B_{avb} = E_{avb} \quad (21)$$

Since it is the exact amount BESS stored energy that can be used.

As the sub-grid begins to supply electricity to its electrical loads using the solar plant, the BESS begins to releases some of its stored energy (**B_{rel}**) as the loads draw current (**I_{disch}**) in Amperes from the BESS.

Therefore,

$$B_{rel} = I_{disch} \times V_s \times T \quad (22)$$

Where **I_{disch}** is the measured discharge current in Amperes.

V_s is the System Voltage in Volts.

However, at any point in time (**t**), that current (**$I_{disch.}$**) is being drawn from the BESS, the BESS energy remaining (**B_{rem}**) is given by

$$B_{rem} = B_{avb} - B_{rel} \quad (23)$$

(23) is applicable only when there is no replacement from the solar-PV modules, like in night scenarios, when there is no solar energy.

However, in the day time, as current (**I_{disch}**) is being drawn from the battery banks; solar energy replenishes some or all of the drawn current via (**I_{charge}**).

Where **I_{charge}** is the charging current (measured in Ampere) from the PV modules.

Therefore the energy being replaced back into the battery bank (**$B_{rep.}$**) is given by

$$B_{rep} = I_{charge} \times V_p \times T \quad (24)$$

Where V_p = solar-PV voltage

Therefore **B_{rem}** in the day when solar energy is available is given by

$$B_{rem} = B_{avb} - B_{rel} + B_{rep} \quad (25)$$

Thus, for the solar plant to supply the SPGS sub-grid sustainably,

$$B_{rep} \geq B_{rel} \quad (26)$$

If $B_{rel} > B_{rep}$

Then the solar energy supply to sub-grid will shutdown with time if nothing was done. The LIA at the scenario triggers the intelligent load shedding protocol to ensure that the goal of the LIA is achieved.

So at any point in time (t), the LIA monitors to ensure that

$B_{rep} \geq B_{rel}$

Else

Intelligent load shedding Protocol is initiated by the LIA.

3.3.2 The LIA Control Algorithm

From (26) for the solar plant to be able to supply all the load categories,

$E_{avb} > TE_{dem}$ must be TRUE

If $E_{avb} > TE_{dem}$ becomes FALSE AND utility grid energy input is not available, THEN intelligent load shedding algorithm is initiated, to load shed some load categories.

However, if the utility grid is available, then the load categories that cannot sustained from the solar plant should be supplied from the utility grid, while the utility grid recharges the BESS.

IF $E_{avb} < TE_{dem}$ AND Utility Grid is available

THEN Supply $E_{dem(hpl)} + E_{dem(pl)} + E_{dem(lpl)}$

ELSEIF $E_{avb} < TE_{dem}$ AND Utility Grid is NOT available but $E_{avb} > E_{dem(hpl)} + E_{dem(pl)}$

THEN Load Shed $E_{dem(lpl)}$

ELSEIF $E_{avb} < E_{dem(hpl)} + E_{dem(pl)}$ AND Utility Grid is NOT available but $E_{avb} > E_{dem(hpl)}$

THEN Load Shed $E_{dem(lpl)}$ & $E_{dem(pl)}$

ELSIF $E_{avb} < E_{dem(hpl)} + E_{dem(pl)}$ & $E_{avb} < E_{dem(hpl)}$ AND Utility Grid is NOT available

THEN switch to the Diesel Generator (GEN), AND supply $E_{dem(hpl)} + E_{dem(pl)} + E_{dem(lpl)}$

ELSIF $E_{avb} < E_{dem(hpl)} + E_{dem(pl)}$ & $E_{avb} < E_{dem(hpl)}$ AND Utility Grid is NOT available AND GEN is NOT Available

THEN shutdown the energy Supply to the Sub-grid, WHILE monitoring to know when any of the other energy inputs will be available.

Figure 3 : The algorithm that controls the LIA

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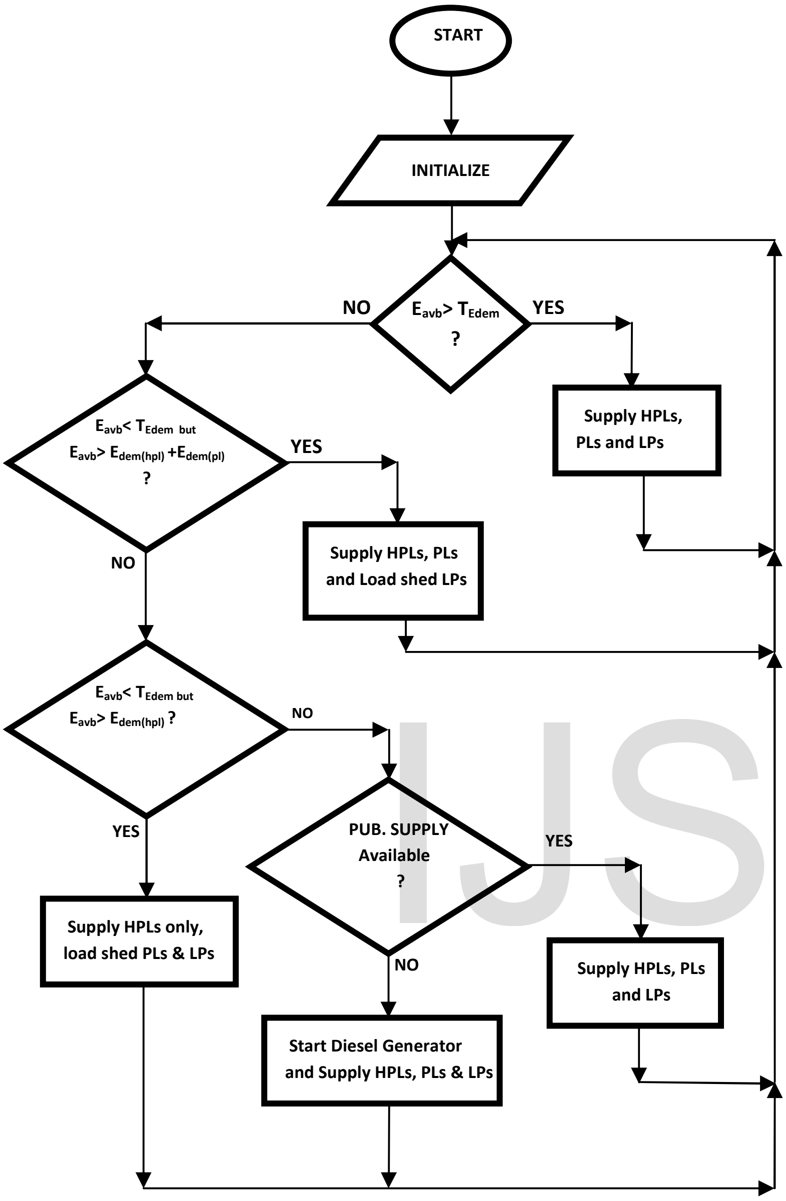
The flow chart for the LIA is shown in figure 4



Note: HPLs =hpls, PLs =pls and LPLs =lpls

Figure 4: The Flow chart for the LIA

4 RESULT AND DISCUSSION

The LIA achieved its goal of providing reliable, cost–effective and steady power supply to sub-grid with the above algorithm. Figure 4 presents the flow chart for the LIA. It clearly shows how the different energy input sources to the sub-grids are selected to supply the different load categories. The primary energy input source to the sub-grids being the solar energy also being renewable in nature, is the cheapest source and thus overrides all the other energy sources once it is available and has enough energy to supply all the load categories. The utility grid supply is not engaged as long as there is enough solar energy within the sub-grid to supply all load categories, even when it is available. The diesel GEN serves as a standby source to the sub-grid, that is automatically engaged when, the solar energy is unable to supply at least the high priority loads. This algorithm ensures a cost effective approach in the running of the sub-grid, while delivering a reliable and steady power supply. In this way, high efficiency in the management of available energy is ensured. The LIA is an autonomous intelligent agent and runs the SPGS sub-grid mostly in islanded mode, except when it requires extra energy to supply its load categories.

5 CONCLUSION

The LIA model is a multi-function intelligent Agent which manages the Energy in SPGS sub-grid Nnamdi Azikiwe University Awka, Anambra State Nigeria, to ensure the delivery of a reliable, cost-effective and steady electricity power supply system. It achieved this by employing the developed LIA algorithm developed in figure 3.

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