Location-Based Intelligent Power Generation and Management Algorithms for Physically Challenging Rural Areas

Onabajo Olawale Olusegun and Chong Eng Tan

***Abstract*—Climatic change is one of the driving forces behind a new wave of energy management systems being practiced in different parts of the world today. Power generation and Management in disconnected rural villages is challenging. The situation is even more challenging when landscape structures in such environment are irregular. This paper describes the implementation of two algorithms used in power generation and management of rural energy supplies: Location-based Solar Energy Potential Prediction Algorithm (LOSEPPA) and Intelligent Fuzzy-controlled Power Generation and Management Algorithm (IFPGMA). LOSEPPA takes as input, the geographic latitude of the location to compute the solar irradiance factor. IFPGMA intelligently manages the utilization of the generated solar energy. Geographic latitude plays an important role in the availability of sufficient solar radiation as well as the state of the atmosphere. Therefore, the value of solar irradiance factor serves as a guide to the state of the atmosphere in terms of degree of cloud cover, temperature, humidity and landscape structure; which determines the feasibility of the solar energy implementation. With the solar irradiance factor, solar panel can be mounted along specific angle of inclination to the sun. The implemented design is based on solar PV modules arranged in array, integrated with rechargeable batteries and converter models to drive solar energy generation for powering networking equipments. The proposed system was simulated using Homer energy software, C++ and MATLAB-Simulink.**

Result show that the more irregular the landscape is, the lower the solar irradiance factor. Solar irradiance factor value of 400 and above predicts well enough sunshine for solar PV implementation. Set point values for battery charging/discharging and the charge controller, maintains circuit voltage supplies at 130V maximum and 2KWh/day at $0.735/KWh with an initial investment cost of $3,090 for the solar implementation.

***Index Terms*—Geographic latitude, battery charger, PV panel, voltage regulation.**

I. Introduction

Disconnected rural communities are cut off from government economic transformation agenda as a result of not being connected to the national grid. Many remote residences, businesses and communities located in the sparsely populated and rugged terrains; faces serious challenge in accessing uninterruptible wireless broadband as a result of insufficient electricity supply. Most of the currently available energy management systems in domestic environment are concerned with real-time energy consumption monitoring, and display of statistical and real time data of energy consumption [1]. An alternative energy supply system in the form of solar electricity, supported by indigenous communities has been widely accepted as a provisional escape route for the rural folks from abject poverty caused by digital divide. The stand-alone photo-voltaic energy system is a well tested energy alternative in an environment where grid electricity is completely absent. However, proper functioning of an independent energy source like the stand-alone solar energy system requires storage to meet the energy demand during period of low solar irradiation and night time. To put the acquired energy into proper use, effective and efficient management scheme must be put in place to prevent wastage.

Focus of this paper is on the development of an intelligent system for efficient management of energy consumption of networking equipments in a rural setting. The motivation is to develop resourceful and intelligent power management system that can manage energy consumption of networking equipments effectively to prevent wastage and improve user access to online participations. The entire work is in two stages, and two algorithms were developed for this purpose: (i) Location-based Solar Energy Potential Prediction Algorithm (LOSEPPA); and (ii) Intelligent Fuzzy-controlled Power Generation and Management Algorithm (IFPGMA). The proposed system identify solar potential of a location, generate and actively manages energy usage in such environment in real time and ensure power consumption to idle terminals are minimize after a given time of idleness. The algorithm uses fuzzy logic approach to monitor energy consumption at appliances and device level. LOSEPPA takes as input the geographic latitude of the location, and compute the solar irradiance factor of the landscape through gradient and aspect estimation on per kernel basis. The solar irradiance factor is a reflection of the solar potential of the landscape. IFPGMA applies fuzzy logic approach in the intelligent control of power to PC terminals and devices.

II. Related Work

Despite the fact that energy reclamation mechanisms can be adopted to recharge batteries through solar panels,

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energy is a limited resource and must be used judiciously. Hence, efficient energy management strategies must be devised for networking equipments to prolong network lifetime as much as possible. Several research efforts have been carried out in recent years to design smart home environment where various appliances forms home area network. Home automation technology and ubiquitous wireless communication protocols provide a great potential for home energy management systems to be included in smart home environment. Such an automated environment provides supporting infrastructure for home energy consumption monitoring systems. A number of initiatives have started recently in an attempt to deal with issue of energy management. Yedendra *et.al.* [2] proposed an energy management system called Yupik. The aim of the Yupik system is to optimize the interaction among three components: a consumption profiler that collects information; an analytics engine that identifies trends as well as gives suggestions to reduce consumption; and a user interface that provides an overview of the trends and suggestions; and from the result, conserves energy consumption at homes. The aim of the Yupik system is to provide a higher-level overview and recommendations to reduce energy consumption by considering demand response and performance of appliances. Component-wise, Yupik system captures the energy consumption at homes and creates awareness about the trends in consumption pattern as well as provides suggestions to reduce the consumption. In this work, energy consumed by individual appliances is measured using smart plugs known as jPlugs. These plugs look like normal power strips and have a single power socket. The appliance that needs to be monitored can be plugged into that socket and the jPlug in turn gets plugged into wall sockets. A consumption profiler stores the data from the appliances. Analyzing the data collected from the consumption profiler reveals important information on how often and when certain appliances were used over a time period and their performance details can be estimated.

[3] describes the design and implementation of an intelligent traffic lights controller based on fuzzy logic technology. Control software was developed to simulate the situation of an isolated traffic junction based on this technology. Fuzzy logic technology allows the implementation of real-life rules similar to the way humans would think. The software is particularly graphical in nature, and uses the Windows system which allows simulation of different traffic conditions at a junction. A comparison was made between the fuzzy logic controller and a conventional fixed-time controller. Results from the simulation analysis based on waiting time, vehicle density, and cost shows that the fuzzy logic controller has better performance and is more cost effective.

Power management generally enables a computer to enter reduced power states such as standby or sleep mode. So far, the best known power management guidelines are those set by the U.S. Environmental Protection Agency (EPA) Energy Star program [4]. Desktop computers that meet EPA Energy Star guidelines power down to no more than 15 percent of maximum power usage while in sleep mode. Computer models registered with EPA Energy Star typically consume between 5 and 25 W in sleep mode. In this work, it was pointed out how important it is to understand the purpose of Energy Star computer guidelines, which is to reduce wasted energy while computers are idle, such as power consumed by office computers left on overnight. Furthermore, this work confirmed that computer products that are compliant with Energy Star guidelines are not necessarily energy efficient or of low power during normal operation. The work of [5] was based on the development of Sustainable Power for Electrical Resource (SuPER). In this work, the idea is to provide low-cost, sustainable power for individual household with 20 years life cycle. The SuPER system was designed to power a 12V DC load. The basic components of the SuPER project include: Photovoltaic module, lead-acid, battery, shunt, charger, DC-DC converter, switches, and Maximum Power Point Tracking (MPPT) sub-units. The system is designed to generate 400Wh per day with an input solar radiation of 4KWh per day.

III. Algorithm Implementation

Implementation of this work is divided into two parts: (A) Location-based Solar Energy Potential Prediction Algorithm (LOSEPPA); and (B) Intelligent Fuzzy-controlled Power Generation and Management Algorithm (IFPGMA).

A. Location-Based Solar Energy Potential Prediction Algorithm (LOSEPPA)

Rural landscapes with spontaneous mountains and hills require additional input parameters such as geographic latitude, nature of the landscape (direct effect on radiation scattering), and prevailing cloud condition when implementing solar energy projects. Irregular landscapes have slopes and aspects that provide additional information on the nature of the surface. There are several methods for calculating slope and aspect from gridded Digital Elevation Models (DEMs). Generally, their determination is based on neighborhood estimation where calculations are made for a cell based on the values of the cells that are spatially adjacent in the grid [6]. One of such methods is the Four Closest Neighbor (FCN) technique which is used in this paper. FCN uses the four cardinal neighbors; those to the north, south, east and west, to estimate slope and aspect (equations 1 and 2) for an irregular surface. The elevations at these four closest neighbors are used to define two orthogonal components of slope, the slope in x and y, which define the steepness and downhill direction at the point of interest [7].

$$\text{Slope at each grid kernel} = \sqrt{\left(\frac{\partial z}{\partial x}\right) + \left(\frac{\partial zz}{\partial y}\right)^2} \qquad (1)$$

$$\text{Aspect} = \tan^{-1}\left(\frac{\partial z / \partial x}{\partial z / \partial y}\right) \qquad (2)$$

Fig. 1 depicts the simulation model development process for LOSEPPA. One cell is approximately 200 sq meters. Therefore one kernel is 600 sq meters. LOSEPPA takes as input the geographic latitude of the location, and compute the solar irradiance factor of the landscape through gradient and aspect estimation on per kernel basis. The solar irradiance factor is an indication of the solar potential of the landscape. Results show that solar irradiance factor of 400 and above predict well enough sunshine for solar energy generation.

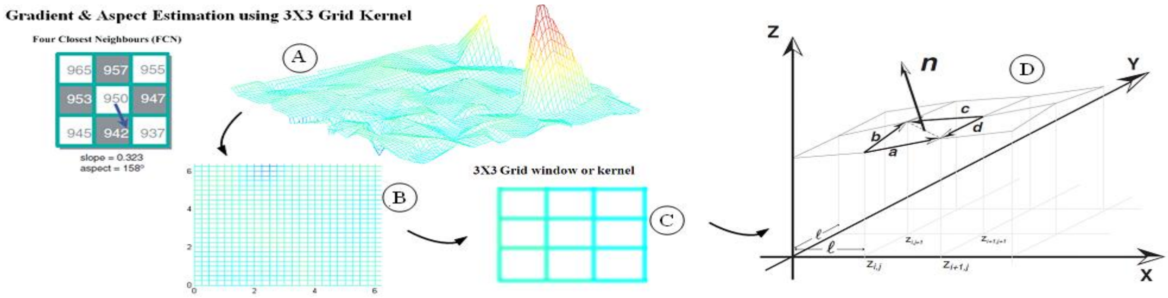

Fig. 1. LOSEPPA algorithm implementation

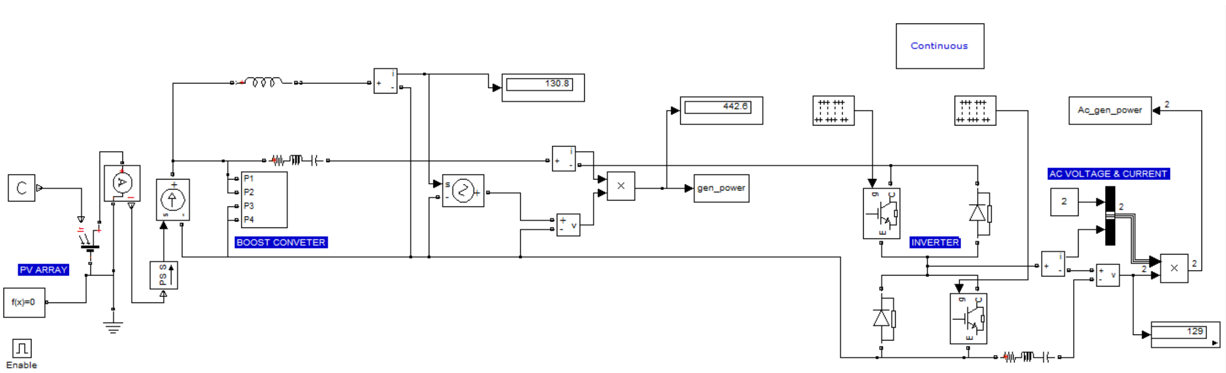

Fig. 2. PV array, boost converter, inverter, AC voltage & current measurement unit

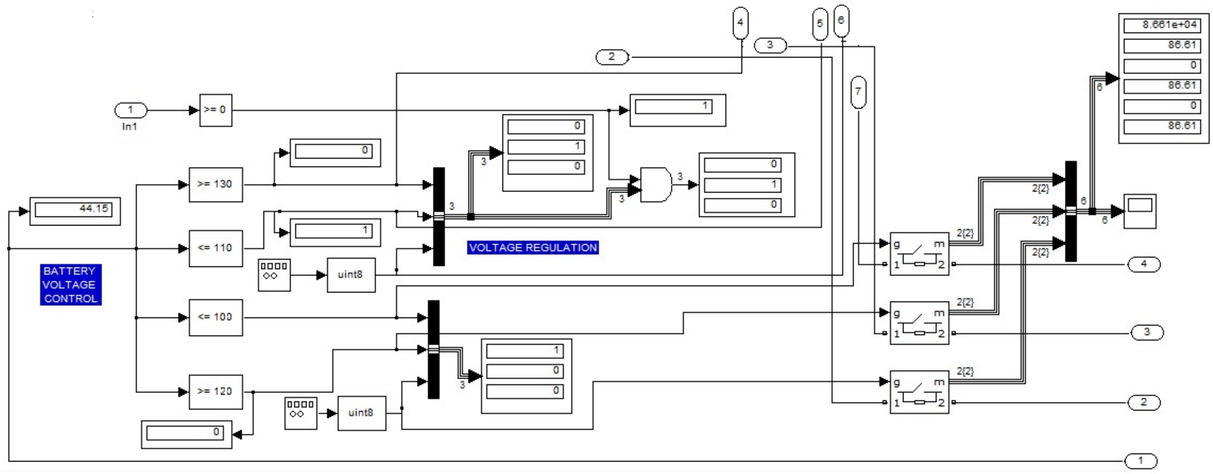

Fig. 3. Battery voltage control and regulation unit

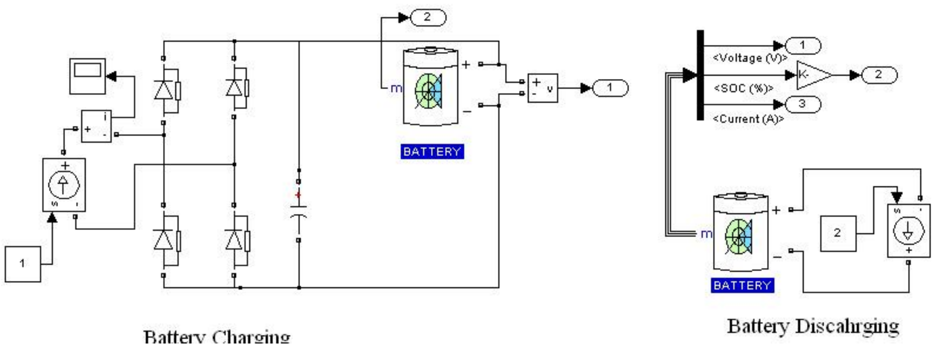

Fig. 4. Battery charging and discharging units

B. *Intelligent Fuzzy-Controlled Power Generation and Management Algorithm (IFPGMA)*

IFPGMA is an intelligent algorithm designed to control power utilization of devices at user terminals within the tele-center using fuzzy logic. Fig. 2 is the PV array, boost converter, inverter, AC voltage and current measurement unit. Solar radiation falling on the solar panel is converted to usable DC voltage by the boost converter. The Inverter converts the DC voltage to AC voltage.

In Fig. 3, current battery voltage is 44.15V. Four switches control the battery voltage to avoid overcharging or undercharging. The regular voltage support to home appliances is 130V maximum (US standard). The '*compare to constant*' blocks applies sensitivity to the voltage control. The Voltage Regulation Limit (VRL) is the maximum voltage up to which the battery can charged. If this point is reached, the charger disconnects the battery from PV array. The Low Voltage Elastic Return (LVER) is the difference between VRL value and the voltage at which the charger reconnects the battery to the PV source and starts charging. It also determines how effectively the charger can control the battery. The Low Voltage Disconnect (LVD) is the minimum voltage up to which the battery can be allowed to discharge, without getting deeply discharged. LVDER is the difference between LVD value and the battery voltage at which the solar arrays can be reconnected back to the battery. Table I is a list of the control points.

TABLE I: BATTERY VOLTAGE SET POINTS FOR CONTROLLER

S/N	Parameter	Control Point Values (V)
1	Voltage Regulation Limit (VRL)	130
2	Low Voltage Elastic Return (LVER)	110
3	Low Voltage Disconnect (LVD)	100
4	LVD Elastic Return (LVDER)	120

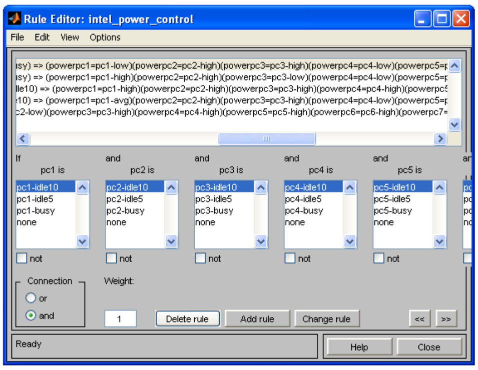

Fig. 5. Mamdani-type fuzzy logic rule editor

Fig. 4 is the battery charging and discharging units respectively. The direct DC voltage from the boost converter goes through the control unit to feed the battery during charging. When battery voltage is at maximum value, voltage from the solar panel through the control unit directly supports networking equipments. The control unit (Fig. 4) prevents under and overcharging of the battery through control value set points shown in Table I.

Fig. 5 is the rule editor for the fuzzy logic implementation. IFPGMA intelligently monitors idle terminals for 5 minutes and reduce power consumption to 30%, and for another 10 minutes reduce power consumption to 20%. Assumption made in the IFPGMA design is that the number of PC terminals at the tele-center is 10.

IV. RESULTS AND DISCUSSION

For the IFPGMA algorithm, result show that the more irregular the landscape is, the lower the solar irradiance factor. Scattering at the surface of the landscape are possibly responsible for this observation. Solar irradiance factor value of 400 and above predicts excellent sunshine hours for solar energy project implementation. Simulations carried out with different landscape structures follow the graph pattern in Fig. 6.

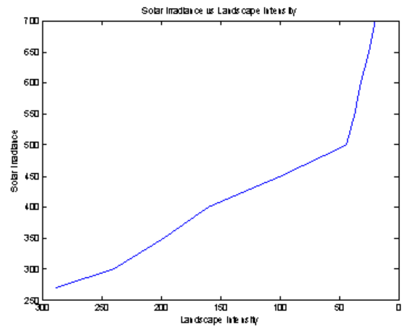

Fig. 6. Plot of solar irradiance factor (SIF) against landscape intensity

Fig. 7 is the simulation model for the solar PV implementation. Homer Energy is a software designed to simulate costs of renewable energy implementation (solar, wind etc). Homer software comes out with various options available for consideration based on user inputs. From Fig. 7, option one has 2 PV panels (1KW capacity each) with 8 L16P batteries (6V each) have an initial capital cost of $2,913. Option 2 is three PV with 8 batteries (6V each) with implementation cost of $3,090 etc. Best option based on costs and value selected by Homer after simulation was 3 PV with 8 batteries at a cost of $3, 090. Fig. 8a is the AC current and voltage load, and Fig. 8b is the voltage switching and control.

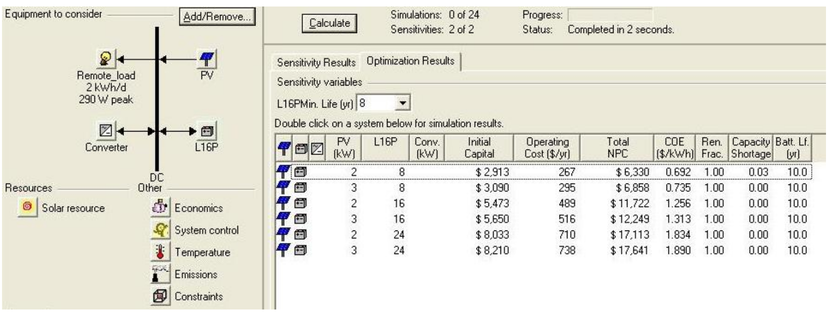

Fig. 7. Simulation model using homer energy software

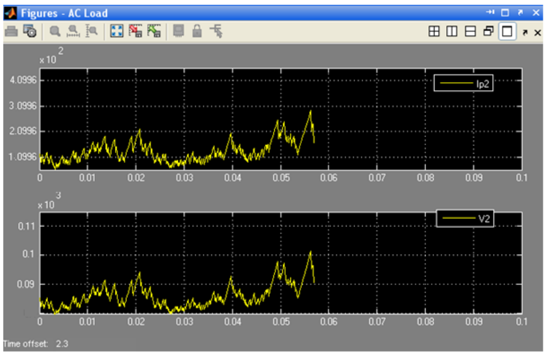

Fig. 8a. AC current and voltage load

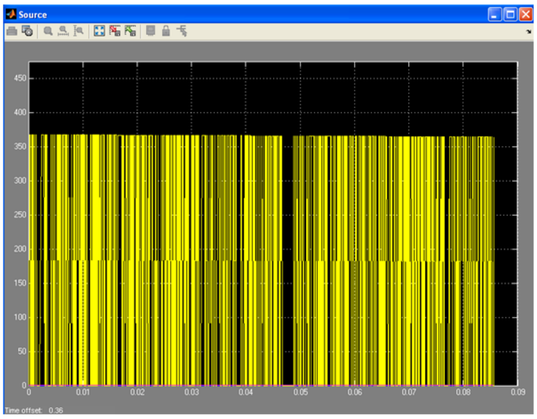

Fig. 8b. Voltage switching and control

V. Conclusion

From the simulation results, solar irradiance factor of 400 and above predicts good weather for solar PV implementation in regions with irregular landscape. Most viable cost of implementing a small scale project like the one under consideration based on Homer simulation software is $3, 090 for Two PV panel of 1KW capacity and with eight 6V batteries.

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