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Full Length Research Paper

Intelligent power generation and management algorithm for rural tele-center application

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The need to develop resourceful and intelligent power generation and management system to prevent energy wastage in rural telecenters is evident because no grid support is available, and existing system are only functional for short period and specific time of the day. This paper describes the implementation of an algorithm used in power generation and management of rural power supplies: Intelligent Fuzzy-controlled Power Generation and Management Algorithm (IFPGMA). The algorithm development is based on integrating solar PV modules arranged in array, integrated with rechargeable batteries and converter models; with intelligent control of power at PC terminals and device level to drive solar energy generation and management for powering networking equipments. Functionality of IFPGMA is in two parts: (a) energy production, which involves the trapping and conversion of solar energy from the Sun to usable form; and (b) power management of telecenter PCs and networking equipments to eliminate wastage. Cost simulation of the solar PV implementation part was also conducted in order to give stakeholders idea on initial capital cost to setup such project. The proposed system was simulated using MATLAB-Simulink, C++ and Homer energy software. Results show that IFPGMA intelligently monitors idle terminals for 5 minutes and reduce power consumption to 30%, and for another 10 minutes reduce power consumption to 20%. 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 project implementation.

Keywords: IFPGMA, Battery, PV Panel, Voltage Regulation

INTRODUCTION

This paper is the second of two papers describing the implementation of intelligent algorithms useful for solar energy potential prediction, power generation and management in mountainous rural areas. 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. 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. Power generation and management in disconnected rural villages is a challenge. The situation is even more challenging when landscapes structures in such environment are irregular. To improve access time to electricity supply in such area, energy accountability with prudent management

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practices is required. Effective and efficient management scheme must be put in place to prevent degradation and uncontrolled depletion of generated energy. Disconnected rural communities are generally 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 (Kuo-Ming et al., 2010). Although these systems play a crucial role in providing a detailed picture of energy consumption in home environment and contribute towards influencing the energy consumption behavior of household, they all leave it to the households to take appropriate measures to reduce their energy consumption. Some energy management systems do provide general energy saving tips but they do not consider the household profiles and energy consumption profiles of home appliances. The stand-alone photo-voltaic (PV) 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. Current work describes the implementation of IFPGMA, a fuzzy logic based algorithm designed to manage generated power from solar PV system for prudent power consumption of networking equipments. The proposed system monitors energy consumption at appliances and device levels.

Background

Provision of basic amenities is undoubtedly insufficient in many rural areas of developing nations including Malaysia. The term rural areas connote underserved region. Underserved communities in most part of the world are communities located in the remote areas of countries with no electricity, water, access to essential public services, or a shortage of such services. Despite the fact that energy reclamation mechanisms can be adopted to recharge batteries through solar panels, 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. Lately, the use of solar PV for energy generation has become popular, especially among the rural people as community project. However, because of small size and the solar PV system being functional only in the presence of sunlight; prudent management of the trapped energy is essential in order to extend network access time.

Solar radiation and PV Cells

A photovoltaic cell is the smallest unit of a PV module that directly harnesses solar energy from the sun. The voltage across a solar cell is one of the main properties that define the photocurrent characteristics of the solar cell. A PV cell is usually embodied by an electrical equivalent of one-diode with diode current I_D, series resistance *Rs* and parallel resistance *Rp* as shown in *Figure 1*.

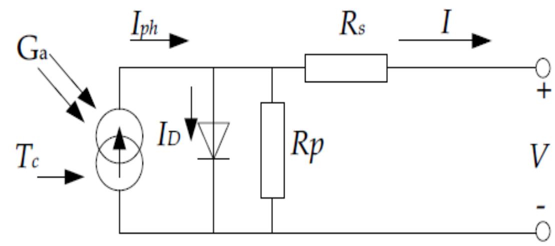

Figure 1. Equivalent circuit of a solar cell with one diode (Gulzar et al., 2006).

The dynamic model of a photovoltaic cell has the following equation (Shaban, 2011):

$$V_c = \frac{AkT_c}{q}\ln\left(\frac{I_{ph} + I_0 - I_c}{I_0}\right) - R_s I_c \qquad (1)$$

Where,
q – Electron charge (1.602×10^{-19} C)
k -- Boltzmann constant (1.38×10^{-23} J/^{0}K)
Ic -- Cell output current (A)
Iph – Cell photocurrent, function of irradiation level and junction temperature (A)
Io -- Reverse saturation current of diode
R – Cell series resistance (ohm)
Tc -- Reference cell operating temperature
Vc -- Cell output voltage (V)
A – Diode quality (ideality) factor
Equation (1) when validated for specific temperature and solar irradiation level, the output voltage and cell photocurrent becomes

$$V_{c\_new} = C_{tv}C_{sv}V_c \qquad (2)$$

$$I_{ph\_new} = C_{ti}C_{si}I_{ph} \qquad (3)$$

Where, C_{tv}, C_{sv}, C_{ti} and *Csi* are correction coefficients whose values depend on the cell temperature and the solar irradiation level.

A number of initiatives have started recently in an attempt to deal with issue of energy management. Artificial Neural Network (ANN) is one of the approaches recently embraced by the research community in the management of power supplied to electrical equipments. Current research employs the use of fuzzy logic in the design and implementation of rural electricity management system.

Fuzzy Logic Concept

Fuzzy logic is a powerful problem solving methodology introduced by Prof. Lotfi Zadeh in the 1960s (Gulzar et al., 2006; Shaban, 2011). Fuzzy logic resembles human decision making with its ability to work from approximate data and find precise solutions. Nowadays, fuzzy logic controller (FLC) have been successfully applied in many fields including automatic focus cameras, household materials such as dishwashers, automobile industry etc. FLC is driven by a collection of verbal rules, often in IF-THEN format. A fuzzy controller uses fuzzy logic to simulate human thinking. The Fuzzy logic technique is based on four basic concepts: Fuzzy set, Linguistic variable, Possibility distributions and Fuzzy if-then rules.

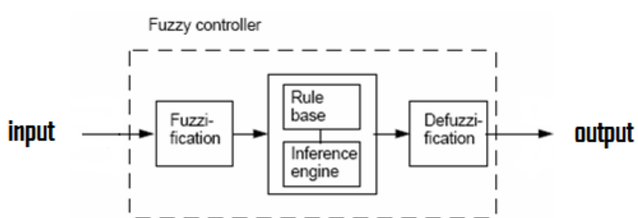

Figure 2: Fuzzy logic controller structure

Fuzzy logic has rapidly become one of the most successful of today's technologies for developing sophisticated control systems. It enables non-control specialists to design control system that works with verbal rules rather than mathematical relationships. FLC has been used in many industrial applications and also power electronic drives in order to improve performance without having to develop mathematical model of the system (Karray and Silva, 2003).

Rather, FLC uses an inference method of human expert knowledge to arrive at specific outcome based on initially defined rules. FLC structure as shown in Figure 2 is made up of five components: input, fuzzification, rule base, defuzzification, and output. The output from the defuzzification process is the expected control function value of the FLC. The task of monitoring power usage at a device terminal cannot be an easy one to model as a result of the various complexities of the system parameters at different states. For instance, power consumption is highly unpredictable because uses vary at each time of the day and each day of a year. Thus, in such a case involving complexity, FLC is very suitable. Fuzzy logic technique is proposed in this work as a way to control power usage at PC terminals and network device level at a rural tele-center. Its major advantage is that expert knowledge can help regulate electricity consumption when incorporated into the fuzzy controller using simple linguistic rules to achieve the control objective without involving the mathematical models of the hardware. Fuzzy logic controllers as used in this paper is designed based on rule table using current voltage status and change in voltage as input variables. Traditionally, computer decision is based on two-value Boolean logic (true/false, yes/no, 0/1), but not all real world problems lend themselves to a strict yes/no or true/false formulation.

Hence, the contribution of fuzzy systems hypothesis is that it provides a systematic procedure for transforming a knowledge base into a nonlinear mapping (Wang, 1997).

Related work

Despite the fact that energy reclamation mechanisms can be adopted to recharge batteries through solar panels, energy is a limited resource and must be used judiciously. Hence, efficient energy management strategies must be devised for networking equipments to extend network lifetime. 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 proposed an energy management system called Yupik (Yedendra et al., 2010). 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 of home devices. 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 a wall socket. 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.

The work of T. DenHerder was based on the development of Sustainable Power for Electrical Resource (SuPER) (Tyson, 2006). 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. Kok Khiang et.al describes the design and implementation of an intelligent traffic lights controller based on fuzzy logic technology (Kok et al., 1997). 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.

K.K Chadella et.al presented the preliminary study of the modeling of a small standalone AC system with the fuel cells and solar panels as energy resources (Chedella et al., 2010). The solar energy is the main energy source for electricity generation during the day and complemented with the fuel cell when needed. The fuel cell and the battery support system are responsible for meeting the electricity demand during the night. The dynamic models of the fuel cell and the photovoltaic cell were implemented in Simulink and the load characteristics were obtained for both.

The proposed system also includes two DC/DC converters to boost the output voltage from both the fuel cell and PV cell to 80V DC. The DC/AC Pulse Width Modulation (PWM) inverter is involved in the conversion of DC to the standard AC voltage suitable for general household appliances. The power management strategy and the load sharing controller are the two main research goal of this paper. When the solar energy is sufficiently high during the day it is used to completely meet the load demands for that period, and excess supplies are backed up in battery compartment for later use. During nights the fuel cell operates independently supplying the required power demand of the load. When there is no sufficient solar radiation both photovoltaic system and fuel cells operate together to share the load demand. The battery is used to support this system during transient period when the response of the system is not quick enough to meet the change in load demand. Result from the simulation shows the feasibility of including dynamic models of the renewable energy resources in the analysis of the system performance.

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 (Karlgren et al., 2008). What is lacking in all previous work considered is the prudent management of the available energy. Current research is aimed at addressing this shortcoming.

The proposed IFPGMA implementation

F. J. Proenza defined telecenters as shared premises where the public can access information and communication technologies (ICTs) services (Proenza, 2001). The idea about telecenter establishment among rural communities is not new. Though some telecenters still use diesel generator, larger percentage now uses small scale solar energy plants for daily activities. The algorithm described in this paper is designed for the management of solar electricity generated for the telecenter usage. The algorithm design is a two-step process: (a) Solar PV Implementation, and (b) IFPGMA Control System Model

Solar PV implementation

The Matlab model of the solar panel was designed based on the design in Training Program for Contractors. This project is a small scale project with only few hundred watts of generated power. The goal of the research is to power mainly the PC terminals at a rural telecenter. Calibration of the PV module is based on details from literature. One silicon solar cell produces 0.5V. Thirty six (36) cells are connected together in series to form a PV module. Modules are the building blocks of PV panels and arrays. One PV panel is made up of three standard modules, with each module containing 36 PV cells connected in series. Each module is capable of generating 18 volts.

Therefore a single panel generates 54 volts. By design, due to solar cell efficiency factor; out of the 18volts originally generated from the solar module, approximately 14volts are usable. This is good enough to charge 12 volts battery. For this work, three (3) solar panels where connected in series to yield approximately 42 volts, and with DC-DC boost converter the voltage is stepped up to regular grid capacity. The current through a dynamic solar cell can be obtained from equation (4)

$$I = I_S(e^{Va/Vt} - 1) - I_{ph} \quad (4)$$

where *Is* is the saturation current of the diode and *Iph* is the photo current (which is assumed to be independent of the applied voltage *Va*). This expression only includes the ideal diode current of the diode, thereby ignoring recombination in the depletion region (Wikipedia, Power Supply Unit (Computer), 2012). The short circuit current, *Isc*, is the current at zero voltage which equals *Isc* = -*Iph*. The open circuit voltage is then given by:

$$V_{OC} = V_t \ln\left(\frac{I_{ph}}{I_S} + 1\right) \cong V \ln \frac{I_{ph}}{I_S} \qquad (5)$$

V_{OC} is the open circuit voltage; *Vt* is the voltage at temperature t. The total power dissipated in the circuit is also given by:

$$P = V_a I = I_S V_a (e^{Va/Vt} - 1) - I_{ph} V_a \qquad (6)$$

P is power generated, *Va* is the applied voltage. Maximum power occurs at $\frac{dP}{dV_a} = 0$. The voltage and current at maximum power point is *Vm* and *Im.*

The input parameters used in the simulation are as follows:

Nc-- Number of cells in series
Np-- number modules in parallel
Nss-- number of modules in series
A-- Diode quality (ideality) factor (1.3977)
k-- Boltzmann constant ($1.38e^{-23}$),
Iscn-- nominal short-circuit voltage
Kp-- voltage temperature constant
Ki-- current temperature coefficient
Vmp-- voltage maximum power at standard temperature condition (STC)
Imp-- current at maximum power at STC

The PV characteristics from the datasheet for BP MSX 120 series PV module with 25 years performance warranty was used to generate the file necessary for *Rs, Rp,* and other parameters for the maximum power point (MPP). The initial setup was used to obtain the I-V curve characteristics of the PV array, which shows the maximum power point of the PV. The model of the PV is used with the boost converter to determine the performance of the maximum power point tracker (MPPT). The Simulink model uses a current source, voltage source and resistance in series and parallel of the PV. The number of modules in series and parallel were set with *Nss* and *Np*.

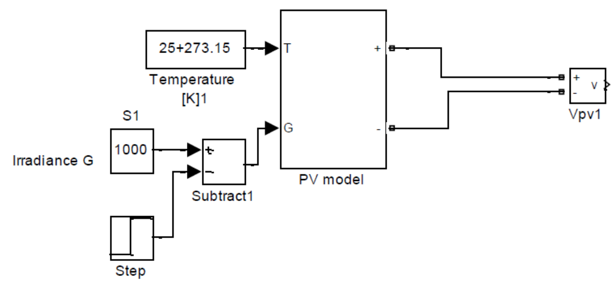

Figure 3. Subsystem representation of the PV model in Simulink.

Figure 3 is the subsystem block representation of the PV panel. This can be used with different power circuits in Simulink. It can be noted that the inputs to the PV are the irradiation and temperature; the outputs are the voltage and the current. Figure *4* 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 and stepped up by the boost converter. The Inverter converts the DC voltage to AC voltage.

In **Figure 5**, 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 be 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 *1* is a list of the control points.

Figure 6 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 (*Figure 5*) prevents under and overcharging of the battery through control value set points shown in Table *1*.

IFPGMA control system model

As mentioned in the earlier section, IFPGMA is an algorithm designed to manage power consumption at PC and device terminals. This section discusses basics of fuzzy logic and how it is used in IFPGMA implementation for power generation and management. The process of power control follows a control algorithm for the interaction among various system components to manage produced energy and prevent wastage. Determining the best condition of operation is the key to achieving optimum operation of IFPGMA. Figure *7* shows the power flow diagram of the FLC with input and output control parameters. The inputs to the controller are the parameters like unpredictable load power and

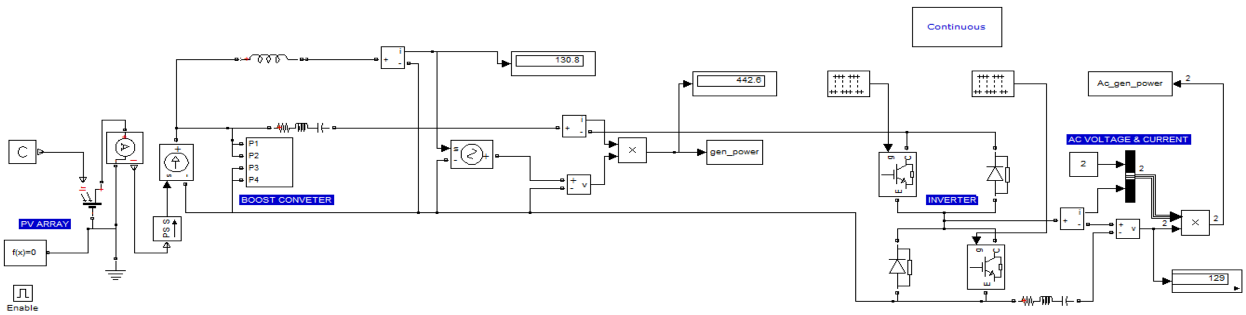

Figure 4. PV Array, boost converter, inverter, AC voltage & current measurement unit

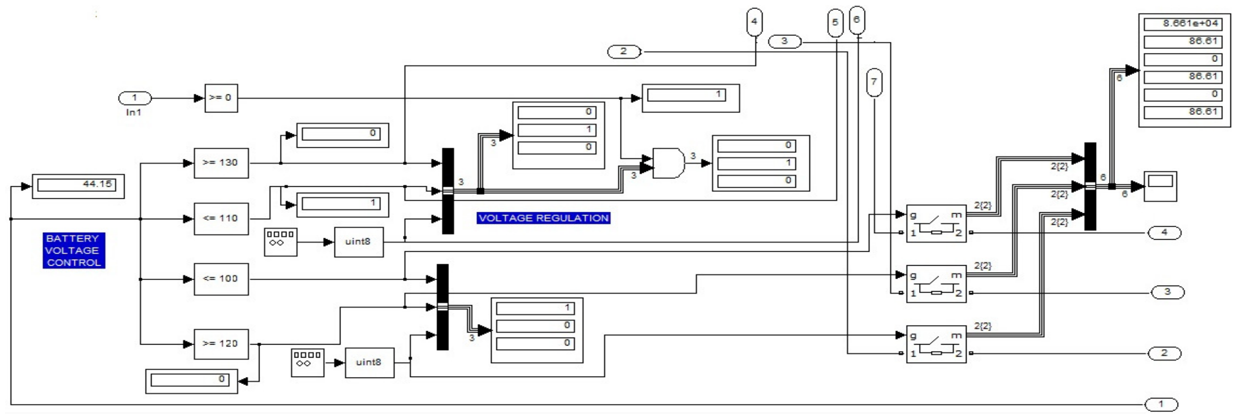

Figure 5. Battery voltage control and regulation unit

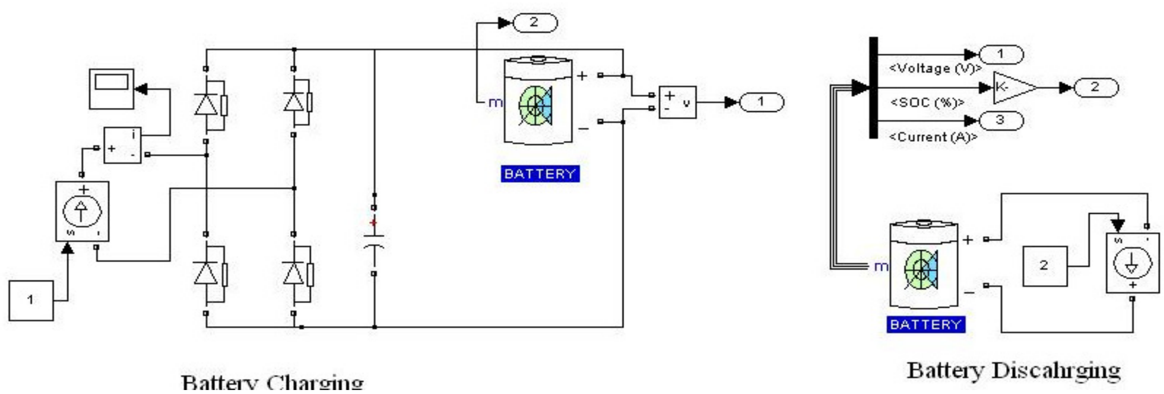

Figure 6. Battery charging and discharging units

renewable varying output energy stored in battery. The output parameters are the PV supply and simultaneously charging operations of the battery.

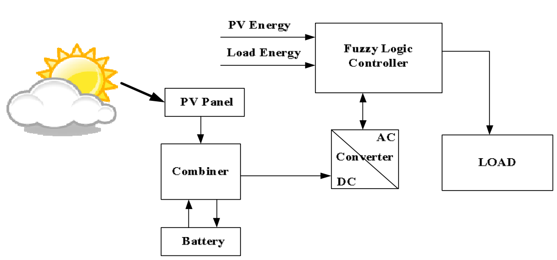

Figure 7. Schematics of IFPGMA Implementation

A vital component to the operation of a computer is the power supply. Power supply units (PSU) are essential hardware components that draw energy from an electrical outlet and convert it into electricity at the proper voltages to power a computer motherboard and other devices. Without it, a computer is just a lifeless box full of plastics and metals.

Figure 8. Power Supply Unit (Wikipedia, Power Supply Unit (Computer), 2012)

Table I. Set points of battery voltage used for charge controllers

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

Table 2. Power Consumption Rating for Devices of Personal Computers (Singh et al., **YEAR**)

+3.3V	DIMMs, Chipsets, PCI/AGP cards, Miscellaneous chips
±5V	Disk drive logic, SIMMs, PCI/AGP cards, ISA cards, voltage regulators, miscellaneous chips.
±12V	Motors, voltage regulators (high output)

The power supply unit (*Figure 8*) converts alternating current to direct current needed by the personal computers. The PSU of a conventional desktop computer is designed to convert regular DC voltage of 120-130 volts into +3.3V, +5V, and +12V DC power to feed its various components. Table *2* is a list of power consumption rating for devices of personal computers.

The PSU generates not only +3.3V, +5V, and +12V, but also –5V and –12V. Usually, the positive voltages are everything in the system, the negative voltage of –5V is used by the Industry Standard Architecture (ISA) bus on one of the pin, so any ISA cards can use it. The motherboard logic typically doesn't use –12V; however, it might be used in some board designs for serial port or LAN circuits. Although older serial port circuits used +/–12V outputs, today most run only on +3.3V or +5V. In this work, emphasis is on the overall power supplied by the PSU and not individual components.

Traditionally, most approaches to power management of the PSU assumed two-state model, active or idle state. The quantity of the power drawn by the PSU from the main AC supply depends on its assumed state. The PSU is the main modeling point of the desktop computer in this simulation. It is assumed that only desktop computers are used at the telecenter in this research. The two-state model relies on two basic implicit assumptions. (i) PSU has only two distinct power status: *active and idle*. The second is that an active PSU always consumes power at constant rate. These assumptions are used in this paper. According to Zedlewsk et.al, every electrical device maintains a quoted manufacturer input power value when in use (Zedlewsk et al., 2012). It derives its power from one of three options: either the voltage is high and current is low; or voltage is low and current is high or voltage and current are normal. The status of the PC terminals per time is what is required in order to control electricity wastage.

Linguistic variables representation

Fuzzy sets can be used to describe the value of variables. A linguistic variable allows its value to be described both qualitatively by a linguistic term i.e. a symbol serving as the name of a fuzzy set and quantitatively by corresponding membership function which expresses the meaning of the fuzzy set. Linguistic terms are used to express concepts and knowledge in human communication, while membership functions are useful for processing numeric input data. As mentioned under power consumption rating of PC devices, PSU generates not only positive voltage but its value could assume a negative dimension depending on the prevailing input voltage characteristics. Voltage swings are intermittent variations of the voltage level on electrical lines. For instance, the negative voltage –5V is routed to the ISA bus on pin B5 for use by ISA cards.

To estimate power consumed, voltage, current and power are linguistically represented as follows:

- If voltage and current is normal, and PC state is active then power supplied is normal.
- If voltage and current is normal, and PC state is idle then power supplied is low.
- If voltage is low and current high, and PC state is active then power supplied is normal.
- If voltage is high and current is low, and PC state is idle then power supplied is low.

Corresponding action taken by IFPGMA is as follows:

- If PC idle and time is T300 then Power=Power*0.3
- If PC idle and time is T900 then Power=Power*0.2

Figure *9* is the schematic of the idle time controlled by fuzzy logic. Assumption made in this work is that by the term *'idle'* we mean the keyboard and mouse which are the basic input devices are temporarily not in use. Once keyboard and mouse do not receive a touch response, PC goes into idleness, and appropriate function is activated to record the idle time. When idle time is 5minutes, power consumption is reduced to 30%, and for further 10minutes, its value is reduced to 20%.

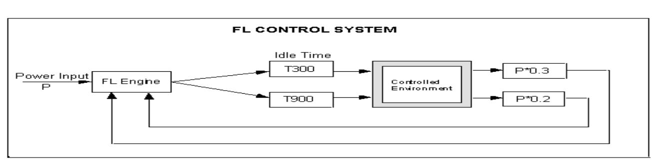

Figure 9. Schematic of Idle time control by IFPGMA

Table 3. Fuzzy Rule Output

Current	Voltage					
		Neg. High	Neg. Low	Zero	Pos. Low	Pos. High
	Pos. High	NH	NH	NH	NL	Z
	Pos. Low	NH	NH	NL	Z	PL
	Zero	NH	NL	Z	PL	PH
	Neg. Low	NL	Z	PL	PH	PH
	Neg. High	Z	PL	PH	PH	PH
	Power					

Table 4: Manufacturer's Max. Current and Power Specification for DELL PS-5141-3D (DELL Technologies Inc., 2012)

Current /Voltage Status	Voltage Rail Range (V)	Max. Current per Rail (A)	Max. Power per Rail (W)
	-12 V	0.3	3.6
	-5 V	0.3	1.5
	+3.3	10.0	33
	+5	16	80
	+12	4.5	54

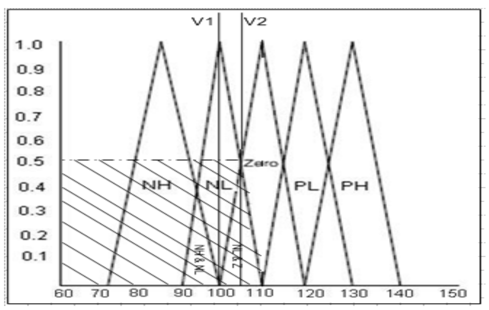

Figure 10: Input voltage membership function

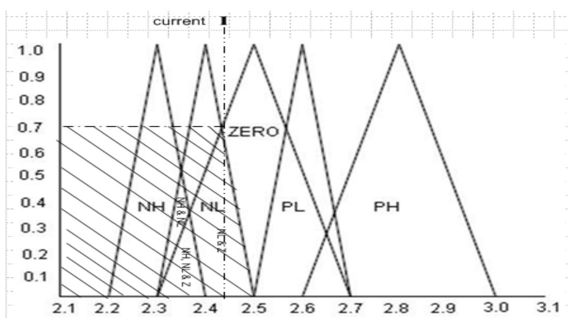

Figure 11: Input current membership function

Voltage supplied to the PSU is defined by a special case of Ohm's law:

Voltage = Current X Resistance ➔ V=I*R (4)

Power supplied to the PSU is also defined by the power law in equation (5):

Power = Voltage X Current ➔ P = V*I (5)

Where *P* is power in watts (*W*), *V* is voltage in volts (*V*) and I is current in ampere (*A*)

The variations in the variable values are the results of the fuzzy rule output shown in Table *3*. Therefore, input status for voltage and current can be linguistically represented as follows:

- Negative High (Neg. High)
- Negative Low (Neg. Low)
-Zero
-Positive Low (Pos. Low)
-Positive High (Pos. High)

This result to rule output displayed in Table *3*. And the coding representation as shown in Table *4*:

Table 4 shows the manufacturer's maximum voltage and current for each voltage rail of the PSU. The overall output power supplied by the PSU is the net value from all the rails as shown in Table *4*. However, for a PSU like DELL with Model PS-5141-3D, DS/N CN -08765D -48010 -08N -1293, the maximum continuous total direct current (DC) output power should not exceed 145W (DELL Technologies Inc., 2012). The net power supplied to the PSU could be low or normal as

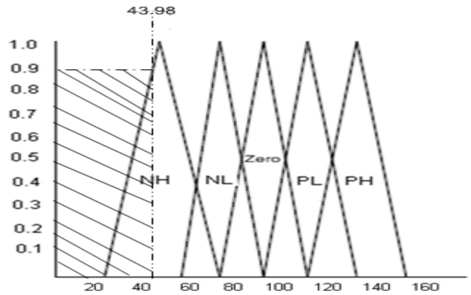

Figure 12. Power output from deffuzzification process

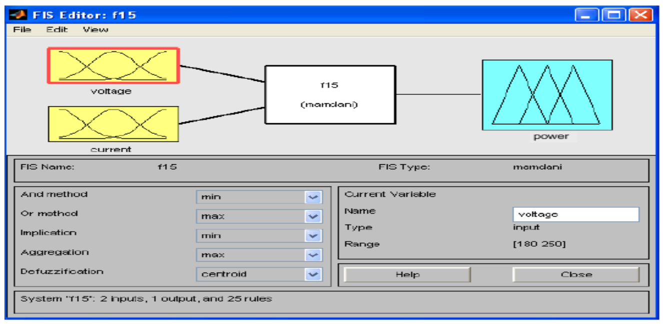

Figure 13. Fuzzy Inference System (FIS) configuration

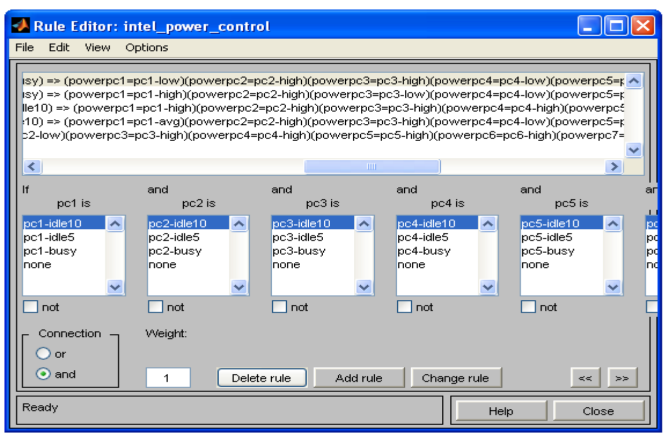

Figure 14: Mamdani-type fuzzy logic rule editor

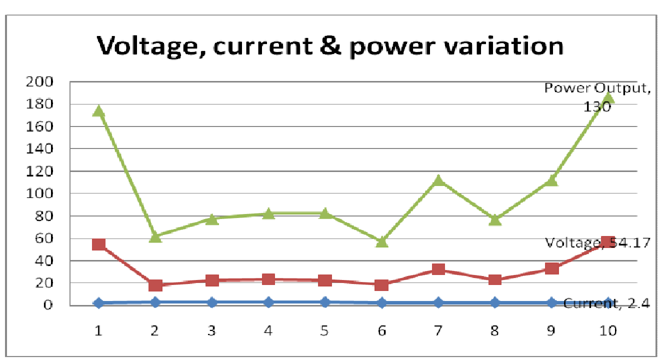

Figure 15. Simulated voltage, current and power variation

mentioned earlier; however, combined operating power on +5V and +3.3V rails should not exceed 85W. It is possible to overload the voltage from a power supply well below the total rating of the power supply. For example, most PSUs create their 3.3 V output by regulating down their 5 V rail of the input. As such, 3.3 V and 5 V typically have a combined limit. A 3.3 V value may have a 10 A rating by itself (33 W), and the 5 V may have a 20 A rating (100 W) by itself, but the two together may only be able to output 110 W. In this case, loading the 3.3 V to maximum (33 W), would leave the 5 V equivalent the only option of being able to output 77 W (Power Supply Unit (Computer), 2012).

The triangular membership function for voltage and current are represented in graphs. Membership function defined for the input variable voltage and current are presented in *Figures 10* and *11* respectively.

Input degree of membership and data difuzzification

The defuzzification of the data into a crisp output is accomplished by combining the results of the inference process and then computing the "fuzzy centroid" of the area. The weighted strengths of each output member function are multiplied by their respective output membership function center points and summed. Finally, this area is divided by the sum of the weighted member function strengths and the result is taken as the crisp output.

There are several defuzzification methods (DELL Technologies Inc., 2012). The center of gravity method converts linguistic variables to crisp values using normalized membership functions and output gains. We can get the fuzzy values for corresponding crisp values by using the membership functions of the appropriate sets. Due to space limitation constraint the figures are not all represented here. Equation (6) is a representation of the centroid method.

$$y = \frac{\int_0^{\varphi} y^i . \mu_B^i (x, y^i) dy}{\int_0^{\varphi} \mu_B^i (x, y^i) dy} \quad (6)$$

Equation (6) when simplified further gives specific range of values as in equation (7)

$$y = \frac{\sum_{i=1}^{N} y^i . \mu_B^1 (x, y^i)}{\sum_{i=1}^{N} \mu_B^1 (x, y^i)} \quad (7)$$

Where y^i are the centers of outcome, μ is the crisp value, *N* is the upper bound. A sample estimation of power is calculated as follows:

We substitute the intersection points from *Figures 10* and *11* into *equation 8* to estimate the power consumption at any instance. In this method, membership function is represented as a vector of numerical numbers. So the fuzzy set consists of range of numerical values for each input and the output is determined for those set of values only. For instance, if input voltage value changes from 100V to 105V based on *Figure 10*, which results to change in current from 2.10A to 2.45A (*Figure 11)*, to find the operating power at that instance, we substitute the intersection points from the figures into equation (7) using center of gravity deffuzzification method:

Power P ➔

$$\frac{(Neg.High * \mu_{23} + Neg.Low * \mu_{13} + Neg.Low * \mu_{22} + Zero * \mu_{12})}{\mu_{23} + \mu_{13} + \mu_{22} + \mu_{12}} \quad (8)$$

μ_{23} = 0.4*0.5, μ_{13} = 0.35*0.50, μ_{22} = 0.35*0.70, μ_{12} = 0.4*0.7

Therefore, Power output =

$$\frac{100*0.20 + 105*0.175 + 2.10*0.245 + 2.45*0.28}{0.90}$$

= 39.584/0.90 ➔ 43.98%

Low power output confirms IFPGMA appropriate power management control as shown in *Figure 12*. For 5 minutes power consumption is reduced to 30%, and for another 10 minutes reduces power consumption to 20%. *Figure 13* is the fuzzy inference system configuration. *Figure 14* is the rule editor for the power management. Assumption made in the IFPGMA design is that the number of PC terminals at the telecenter is 10.

RESULTS AND DISCUSSION

Results show that IFPGMA intelligently monitors idle terminals for 5 minutes and reduce power consumption to 30%, and for another 10 minutes reduce power consumption to 20%. When solar energy is sufficiently high during the day it is used to completely meet the load demands and excess stored in battery compartments. At night, battery support is used to meet the required power demand of the load. When there is no sufficient Sun both photovoltaic system and battery operates together to share the load demand. In an environment where conventional grid supply is completely absent, sufficient battery support is required in order to store enough energy for use at later time when solar radiation from the Sun will not be available. This is an important consideration during initial planning and costing decision. Figure 15 is the simulated plot of voltage and current as well as the output power produced. Normal power supply unit takes an input voltage of maximum 130 volts AC from the main and stepped down into various earlier mentioned DC rail voltage sizes (+3V, +5V, +12V). In this research emphasis is not on the individual rail voltage and current, but on the overall power outputted by the PSU. The power output result shown in Figure 15 agrees with DELL Technologies Inc. that maximum power output by the PSU should not exceed 145W (DELL Technologies

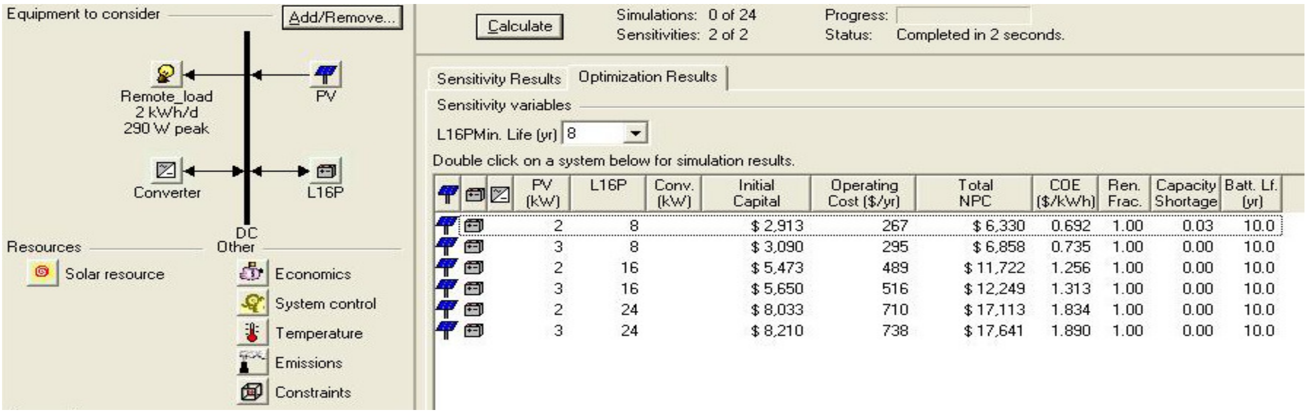

Figure 16. Simulation model using Homer Energy Software

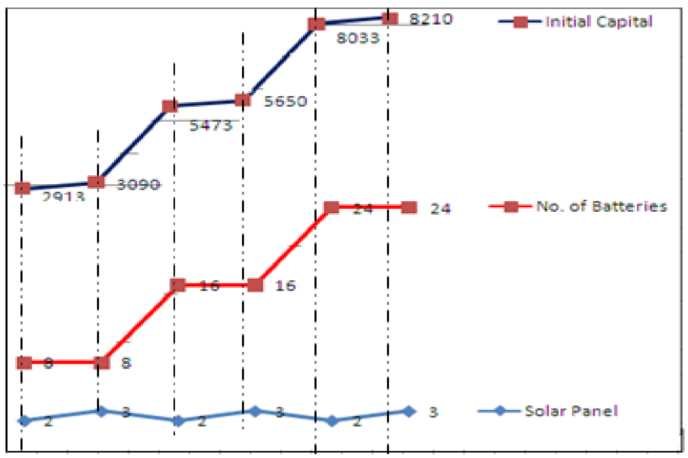

Figure 17. Cost Implication of increasing the number of solar panels and batteries

Inc., 2012).

Figure 16 is the cost simulation model for the solar PV implementation. Homer Energy is a software designed to simulate costs of renewable energy implementation (solar, wind, geothermal, biomass etc). In the course of simulation, Homer energy software comes out with various options available for consideration based on user inputs. From Figure 16, option one has 2 PV panels (1KW capacity each) with 8 L16P batteries (6V each) with an initial capital cost of US $2,913. Option 2 is three PV with 8 batteries (6V each) with implementation cost of US $3,090 etc. Best option selected based on cost and efficiency by Homer after simulation is the 3 PV with 8 batteries at a cost of US $3, 090. The three PV option will provide extra surface area for increased energy harvesting at an additional cost of US $177. If access to funds will not be a concern, the 3 PV option is preferable. Figure 17 is the cost implication of increasing the number of solar panels and batteries with respect to initial cost of implementation.

A close comparison to this work is the effort of S.N. Singh et.al (Singh et al., YEAR). This paper presented the application of fuzzy logic in power failures. The uncertainty in power failures was formulated by fuzzy logic theory through membership functions, which usually do not use strict boundaries, and such a feature was found suitable in dealing with the elusiveness associated with the power failure of the system under investigation. Results obtained shows that combination of diesel generator/grid supplies, as well as radiation from solar panel and stored energy in batteries were appropriately rationed to prevent power failure. Present work is considered more intelligent because it handles rationing of electric power supply between solar panel and stored energy in batteries like Singh et.al. However, in addition, it monitors PC terminals for idleness and take necessary action to reduce power consumption, thereby preventing wastage. Apart from this advantage, other consideration of improved value is the cost estimation and options made available to stakeholders for consideration before embarking on project implementation.

CONCLUSION

Results show the viability of effectively managing rural power supply to the advantage of the rural folks.

IFPGMA intelligently monitors idle terminals for 5 minutes and reduce power consumption to 30%, and for another 10 minutes reduce power consumption to 20%. 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 project implementation.

This work is considered more intelligent compare to other previous work because it handles rationing of electric power supply between solar panel and stored energy in batteries like others. However, in addition, it monitors PC terminals for idleness and take necessary action to reduce power consumption, thereby preventing wastage. Apart from this advantage, other consideration of improved value is the cost estimation and options made available to stakeholders for consideration before embarking on project implementation.

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