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Research paper

Usage pattern monitoring based on battery levels for standalone residential system

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Abstract

Non-availability of constant electricity with the reduction of energy consumption has become important issues for many people, especially those living in areas where there is a problem of electricity. True consumption and timely feedback are essential to support those who want to adjust their behavior in order to conserve energy. In this work, we proposed an interactive system that provides information on the state of the batteries, energy usage pattern in the house and schedule control so that there will be all round electricity rather than occasional blackout. Monitoring and control sensors for stand-alone power generation and control unit are based on three things: electrical consumption data from selected appliances, the time of usage i.e. priority of the appliance and the level of the battery at a particular time. This system will assist to encouragement in the use of renewable energy, especially those that use batteries as their backups such as window solar energy. Also, by self-monitoring for battery level will prolong the time of the system and will save the battery from the high depth of discharge in order to prevent the critical point of no return. Finally, the system can identify the highest consumption appliances and how to minimize the use of such on the battery for renewable energy.

Keywords: *Renewable Energy; Monitoring; State of Charge; Residential.*

1. Introduction

Development in term of economic and social levels of any country depends on the energy availability and its consumption level. Research and development of new sources of power are highly necessary because old sources of power, such as hydrocarbon and big industrial fuel have resulted in a critical situation. Thus, in the world today, the discovery of alternative sources of energy becomes more important and main contributor to the volume of energy consumed. In the UK for instance, electricity is generated from multiple sources like coal, nuclear, combined cycle gas turbine (CCGT), wind, biomass, and others. In addition, the UK imports electricity from neighboring countries. In a day, from midnight to midday, there is an increase in demand of almost 49%. This variation in demand is met by mainly increasing production from coal-fired and CCCGT stations [1]. A similar situation is faced by California electricity demand and supply.

Also, electrical usage in residential and commercial building represents a significant fraction of total energy expenditure. Electricity generated from fossil fuels, which represents a significant portion of the carbon footprint of the occupant and health problems being exposed to need an urgent attention [2]. Access to clean, affordable and reliable energy is necessary conditions for achieving sustainable development in our contemporary world. The above scenario has caused an increase in the demand for solar energy and wind energy by 25 % to35 % over the past 30 years. The market for Photovoltaic (PV) systems is growing worldwide today, such that production of these sources has grown to around 4800 GW. Between 2004 and 2009, grid-connected PV capacity reached 21GW and was increasing at an annual average rate of 60 %. In order to get benefit from the application of PV system, research activities are being conducted in an attempt to gain further improvement in the cost, efficiency, and reliability [1]. Around the globe today a lot of countries are facing the problem of electricity. In most countries in Africa, power consumption has outweighed generation. In West Africa, the problem is so severe that the people don't have access to power for domestic use. Nigeria, which is known as the giant of Africa, with an estimated population of more than 170 million and other economic potentials still suffers from energy poverty, due to lack of development of sustainable energy [4].

Without new technology and renewable energy, the existing energy production capacities will fail to meet the future demand, even if new power plants are constructed. Thus, there is a solution from the supply side like an alternative source of energy which is renewable energy and other attractive alternate which slows down or decreases energy consumption through the use of technology to schedule and drastically increases energy efficiency and removes total break out of no light at all [5]. To manage the limited available power, more often the power has been shared. The principle of power-sharing leaves other areas in total blackout. Instead of power sharing, we can use available power in such a way that only low power consuming devices like bulbs, fan, radio, TV set should be allowed and high power devices like heater pump-set, cooker, refrigerator etc. should not be allowed for that particular period of low state of charge (SOC) of the battery that supplies the alternative sources of power.

Load management is defined as a set of objectives designed to control and modifies the patterns of energy usage of various consumers from the power utility or island and to bring the stability to the whole system. Well, there is no alternative remedies to load shedding or schedule than the increasing power generation or increase the state of charge in island mode. Managing and optimizing available charges, its effect can be minimized. The term control and modification enable the supply system to meet the demand at all times in the most economic manner if they are well implemented [6]. There are several techniques of demand-side load management, such as time shifting [7, 8], manual method, direct load control [9], [10], smart metering and appliances [11-13], time of use, pricing, compensation [14] etc. None of the research works present any load management that considering the SOC of the storage sources to determine the reduction or shifting of loads in the stand-alone system.

Furthermore, to encourage the use of alternative means of generating electricity from photovoltaic (PV), biomass, micro-wind turbine, will require batteries that will serve as backup. Battery energy storage and their application in electricity have become increasingly important, especially in the field of renewable energy [15]. The problem of adoption of the battery on the market is due to lack of a corresponding legal framework, handling, and the cost of the systems. Well, within the past few years, large-scale storage system due to the problem of electricity in most of the countries and utility to provide a primary control reserve have represented a growing business model for storage device [16]. Also to know how important the batteries for storage and primary control reserves for stabilizing grid frequency and maintaining a robust electrical grid. August 2015 the German transmission system operators released strict regulations for providing primary control reserves with battery storage systems as part of regulating the International Grid Control Cooperation region in Europe [17]. These regulations target the permissible state of charge of the battery during nominal and extreme condition which are mainly applied in hybrid form.

Most rechargeable batteries are recognized as the major backbone for both applying distributed power sources and regulating power networks. They are normally used for load leveling, uninterruptible power supply and hybrid renewable power plant [18]. The drawback due to the end- of –life (EOF) criterion which defined as the point where the battery state of the health fall below 80% of its nominal capacity, which commonly used estimate according to the U.S Advanced Battery Consortium. They also concluded that E0F due to aging are not many, but handling or over the drain on the battery was more pronounced [17]. Because, the deeper a battery discharge, the shorter the expected lifespan. There must be a system to monitor and control the use of the battery.

To find a solution to the above challenge, we need a battery monitor and a wireless or wired network that will differentiate between power levels. This will alert the control circuit to switch devices depending on the state of charge (SOC) of the battery at a particular time. The system will consist of battery level sensor, a current sensor, switch circuit, control circuit and communication device which can be wired or wirelessly connected. The system will be such that, the battery SOC level sensor will monitor the battery that supplies energy from alternative power supply to the house and sent the message to the control unit. Also, current measurement devices for each node of the household will supply the usage to the control unit as well. With this, whenever the battery level is low, the control unit will automatically select from the current measurement because of its ability to decide which current is low and high and switches OFF the entire high current consumption devices base on the level of the battery. But if operations are based on wireless communication between the control and the sensors, Zigbee protocol will be employed based on its power consumption that low compared to the other wireless communication [19].

2. Implementation

In Nigeria due to the problem of electricity from the grid, citizen relied on generators to provide short –time power supply. In order to improve the living quality of the residents in rural areas and urban areas where there is a problem of electricity supply, this research is applicable. Apart from the aforementioned, due to health challenges associated with other sources of power supply, there is need to encourage the use of renewable among the people both in rural and urban areas. The monitoring system that proposed to assist the owner to monitor the whole system for proper operation and cost management, will enhance the full use of rich renewable energy resources and improve the battery life and the cost of production. The step by step of the whole system known as intelligent Load Management (ILM) will be analyzed in this section. The whole system comprises of the battery SOC level monitor, Current /power measurement, control unit, and switching circuit. The schematic diagram of connectivity is shown in Fig.1 below:

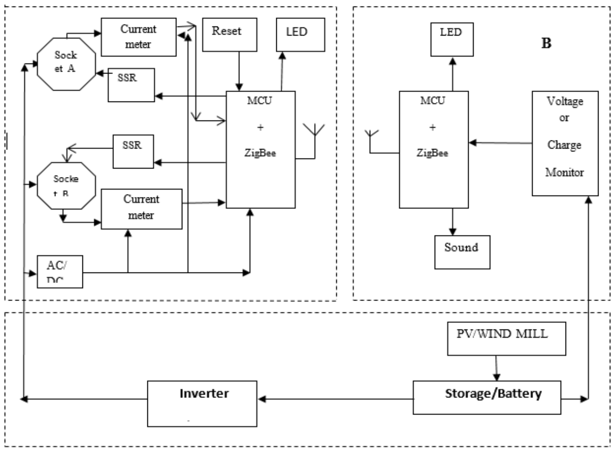

Fig. 1: Block Diagram of the Intelligent Load Management (ILM).

The device will be connected with the island renewable energy power source installed in the household or in an office. The operation of the ILM system is of dual operation i.e. can work using wire line or wireless. But due to the fact that we want to use it for people in the rural area and where there is a problem of electricity, it will be better to use wire connection but can be upgraded to wireless.

The best way to check a battery's condition is through a voltage measurement under load, while the battery is supplying a substantial current through a given circuit. Sometimes, a simple voltmeter check across the terminals may falsely indicate a healthy battery (adequate voltage) even though the internal resistance has increased considerably. What constitutes a "substantial current "is determining the battery's design parameters? Let start with battery state of charge (SOC) estimation for a lead-acid battery that is commonly used in the renewable energy system. The precise SOC estimation prevents a battery from discharging and overcharging. There are several methods to estimate SOC but most common of them is extended voltmeter method that makes use of battery terminal voltage, current, the capacity of the battery and data sheet. The Magnitude of current discharge causes the varying rate of change in terminal voltage and SOC [20]. Generally, an advanced lead-acid battery will last 300 cycles if its cycling is limited to 50% depth of discharge (DOD) [21]. On the other hand, an 80 % DOD limit the cycle life to only 1500 cycles. Due to this is better to maintain the discharge level to a minimum possible. To indicate the levels of the charges on the battery i.e. State of Charge (SOC). The indicator will give the green light at full charge say 100%, yellow light when discharge to two third of the battery charge say 75% and the last one to indicate the average level i.e. 50% of the whole charges.

AC power is not easy to control and likewise to measure like DC because of the danger when power line voltage is being controlled [22]. Measurement of power can be done in a different way like using Ammeter measures current which flow into the voltmeter and load and also another one using voltmeter applied voltage drop across the ammeter in addition to that dropping across the load. But looking at both described above, they are not accurate. But with the help of state of the art electronics like Arduino and AC current sensor IC like AC712 can be a good assistant and with little calculation to get equivalent DC output. This programming way of measuring power for laboratory purpose looks more economical due to its open source software by comparing it to other software which is costlier for example LabVIEW.

Well, all the load in the house is categorized into two, connected and not connected. Not connected are consist of heavy loads like Refrigerator, microwave, cooker, air-condition and the rest. It is advisable not to connect the heavy load such as a motor on to the inverter system for safety purpose. The small load like TV, RadioFan, Lighting and the rest are connected to the system. These are also regrouped into low load and high load after measuring of each appliance in the house, the system will schedule the appliances into low load or high load. This will set as a preset command for the control unit to control the socket based on the power measured from individual appliances. The controller, which consists of microcontroller Arduino and relay devices uses the flowchart in Fig.3 to decide which load to be switched off based on the Charge i.e SOC of the battery at a particular time.

Fig. 2 below summarizes the implementation of power measurement. The circuit consists of the sensors ACT 712 that will detect the signals proportional to the main current and convert them into forming voltage that will be manipulated by the Arduino. The main function of the Arduino is to convert the raw data from original analog input into useful values and then output the signal in serial form with the help of useful software that can run on the Arduino.

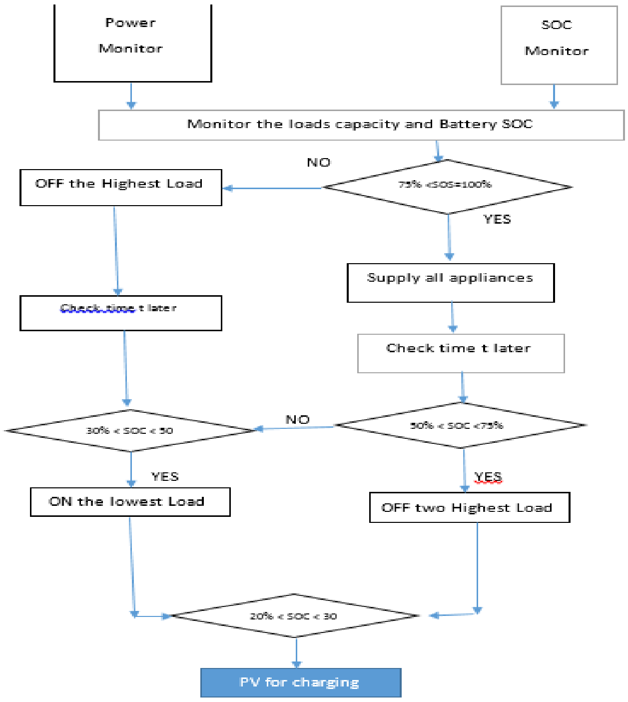

Fig. 2: Flow Chart of the Power Management.

3. Details of the intelligent load management

Arduino UNO is a microcontroller board that based on the Atmega328 as the main controller of the system with a number of connections that allows external sensors like a relay, motor light sensor, loudspeaker, voltage sensor, current sensor etc. The source of power to the Arduino is in two-way either by USB or connected to computer or from a 9V battery. The program to the Arduino is through the USB attached to a computer for upload of the scripts or codes which resemble that of c++ but with significant modification for easy processing that bases on Integrated Development Environment (IDE). The latest version and improvement on the Arduino are making use of an Atmega 8U2 instead of the FTDI-chip before. With the feature of Arduino as in Fig. 3, it can stand alone or communicate with software running on the computer; Also an open –sourceArduino environment makes it easy to write the code and upload it to I/O board, Arduino runs on Windows, Mac OS X, and Linux.

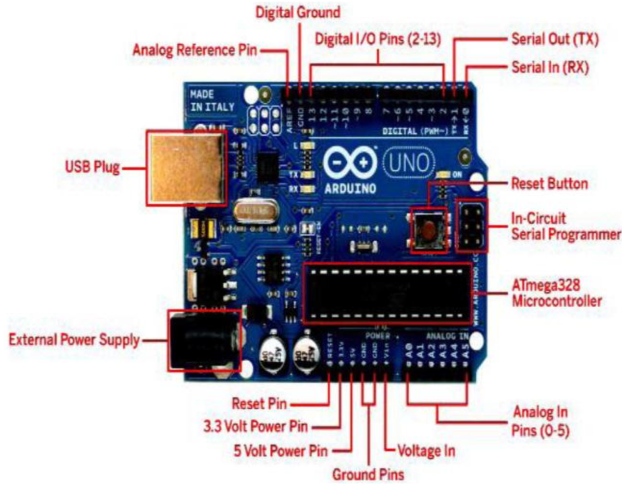

Fig. 3: Arduino UNO Board Sources: https: //www.Arduino.Cc.

Arduino board can be programmed when complex control like predicting or forecasting, control are needed using application of soft computing techniques like Math lab, Neural network, fuzzy logic and Genetic algorithm. Write beautiful code and upload it to the board are extensively used. That is an additional advantage that the Arduino has over other IC i.e Scalability and versatility.

Arduino program is built in such a way that, three inputs need to be fed into it, i.e SOC level of the battery, individual loads, consumption and time of use and output will be that of control to reschedule or switch to low load whenever the battery is discharged to a certain level. Say at a particular time the battery discharge to acertainlevel, the Arduino will look at the history of the appliances and switches in accordance with the priorities set for the whole appliance at that particular time. The program will be written in C language as said to control and monitor the appliances to switch off and on appliances, the voltage sensor measure voltage level of the battery and also current sensor to measure electrical consumption coupled with the history of usage. The programming language will follow the flow chart as in Fig.3.The the main structure of Arduino programming language consists of two basic parts, namely void setup and void loop to run the program.

The Fig.4 shows a detailed blocked diagram of the control unit consist of five components which is AC/DC switching module power, a Current sensor for AC (ACT 712), Energy metering IC, Solid State Relay (SSR) and microcontroller control unit (MCU). Starting from the AC/DC switching module has the function of supplying power to the current sensor, MCU, and other peripheral components by converting AC power to DC power. Current sensor sensing the current in the wire supply to the sockets, then the energy metering IC measure the power consumption of each socket. Then, the MCU will analyze and processes input data and communicates with the server using ZigBee or wired depending on the proximity of the battery. After the receipt of power consumption data from the energy metering IC, the MCU considers whether to switch OFF the sockets or not depend on the value of SOC of the battery set for each power to be low or high in the sockets. The MCU then transmits a control command to each SSR - relays control the sockets in accordance with the transmitted control command.

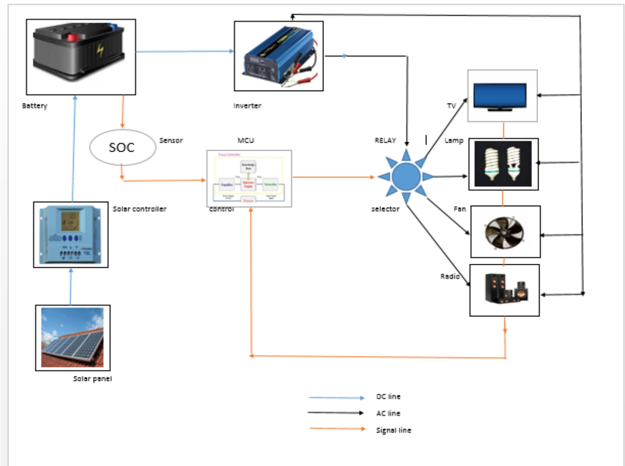

Fig. 4: Block Diagram of the SOC, Current and Power Measurement.

The rest components of the system consist of PV array that collects solar energy and convert it to electricity and battery storage tank for storing the energy which are most expensive components of the system [23]. Other are charge controller from PV array to the battery to checkmate the current into the batter for overcharging but not to stop discharging of the battery. Finally, set of loads that should be controlled to have stable electricity at all time.

4. Practical implementation

In off-grid power management like the one we want to describe, the system consists of two control level: The input control and output control. The charge control serves as input control from the battery to monitor the charge from renewable energy sources to the battery; the function is to avoid overcharging. While the output control constitutes the predictive control of the load on the level of the battery through an inverter to avoid zero power output and prevent low discharge of the battery.

Step A: The system power management algorithm begins with basic information about the appliances in the house:

1) Total consumption of all appliances in the house in Watts.
2) Schedule of the appliances into two group low or high consumption.
3) Time of the day.
4) The appliances priority setting at a particular time.
5) Battery charge /discharge level at a particular time.

Step B: The system using the algorithm to check for battery level, the level of consumption of individual appliances and priority of each appliance that particular time. For battery level, the indicator will show the level of the battery and the amount of load it can carry. For consumption level, the algorithm will use current measurement to check the low or high consumption appliances. The decision to switch OFF/ON can be based on the priority (see Table 2) at the particular time when the battery falls to a certain level in order to adjust the load on it. The whole system then goes through the decision-making process to ensure that all the criteria are met before appropriate appliances can be switched OFF to meet the capacity of the battery. Since there is now total isolation from the PV or charges due to little power from the utility, the battery is expected to charge back or remain on the level until it is charged back to a higher level where all the appliances can go back to ON state.

Table 1: Component of the Off-Grid / Stnd -Alone PV System

Name	Pv	Deep Cycle Battery	Inverter	Voltage monitoring	Current Monitoring
Types	180W	12V/100Ah	12V /1000W	5V/5W	5V/3W
Quantity	2	2	1	1	
Capacity	360 W	2.4 kWh	1kW	5W	8W

Table 1: A) Load Priority Stting for Decision Making Morning - Midday (4.00 Am -12.00 Noon)

Appliances	Usage/Watt	Initial	Final	Duration/Hour	Energy/kWh	Priority
Light	150	5.30	6.30	1	0.150	5
Security light	200	4.00	6.30	2.5	0.500	4
Radio	10	6.00	7.00	1	0.010	1
Lap Top	50	5.00	6.00	1	0.050	3
Charge point	30	5.30	7.00	1.5	0.045	2
Ds-tv/TV	120	6.30	7.00	0.5	0.06	6
Total	560				0.815	

Table 2: B) Load Priority Stting for Decision Making Afternoon - Night (12.00 Noon - 4.0 AM)

Appliances	Usage/Watt	Initial	Final	Duration/Hour	Energy/kWh	Priority
Ds-tv/Tv	120	6.00	10.00	4	0.480	5
Charge point	30	5.30	10.00	4.5	0.135	7
Lap Top	50	7.00	10.00	3	0.150	6
Radio	10	6.00	8.00	2	0.020	3
Fan	60	6.00	10.00	4	0.240	1
Security light	200	7.00	4.00	9	1.800	4
Washing Machine	250	7.00	8.00	1	0.250	2
Total	720				3.075	

5. Conclusion

Most of the earlier smart meters and power management projects focus on the household connected to the grid and most components get their sources from the utility. Also, most of the house energy management system (HEMS) is based on minimization of the cost for both generation and bill on the part of the customers. Our system focussed on urban areas where there is problem of electricity and rural area in Nigeria. Secondly, it helps both the urban and rural dwellers to embrace renewable energy. By reducing the cost of replacement of the battery through improving the life span of the battery. Both the owner and the system will benefit differently, owner comfort will not be affected and economically the owner will have a longer service period. On the part of the system, the system will have longer operating power without being stressed and overloaded unnecessarily and also battery life will be significantly extended than when there is no control. The project will benefit both owners and the system by installing within the requirement of the system in order to get necessary output.

The battery monitor will be sending the amount of voltage or charges on the battery to the control device unit from time to time. The control device unit receives the message and look at the past usage pattern of the components at that particular time and try to reschedule them in order of priority to minimize the output power is proportional to the available power on the system i.e. SOC. The control unit decided to cut the highest load with less priority at that time. Meaning, the owner’s comfort is put into consideration. In this way, the system will be able to manage the available charges on the battery at that particular time until the charges or the voltage increase then add to the load again accordingly, without disturbing the owner comfort. Able to achieve this, the system will be useful to encourage the user to embrace the renewable energy and contribute to the reduction of emitting of CO into the atmosphere from other sources of energy.

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