Journal of Information Sciences and Computing Technologies(JISCT)
ISSN: 2394-9066

SCITECH
RESEARCH ORGANISATION|

Volume 7, Issue 2
June 05, 2018

Journal of Information Sciences and Computing Technologies
www.scitecresearch.com/journals

A Wireless Sensor Network Based Solar Powered Harvesting System for Aquaculture

Daudi S. Simbeye
Dares Salaam Institute of Technology, Computer Studies Department, P. O. Box 2958 Dares Salaam, Tanzania

Abstract

Despite improvements in battery technology and declines in electronics power demands, many new applications in wireless sensor networks (WSNs) are taking into account increasing power requirements. Furthermore, since in WSNs it is frequently desirable to deploy nodes in unobtainable places, it might be impossible to provide large enough power for such applications given the fact that battery replacement is not practicable. This results in significant interests in designing sensor nodes with the capability of extracting electrical energy from surrounding ambient sources. The ultimate goal of this research is to achieve a perpetually powered system without a necessary periodical maintenance for battery replacement or recharging. The energy harvesting system developed for this research has been experimentally verified and can increase the lifetime of an entire network to reach that of its individual hardware components. We realized a maximum power point tracking (MPPT) algorithm that could switch power source according to light conditions to ensure the continuous stable operation.

Keywords: WSN; solar energy; MPPT; aquaculture.

1. Introduction

The energy source of a wireless sensor node is commonly a battery with limited energy budget [1, 2]. For applications where the system is expected to operate for long durations, the energy plays a vital role; therefore, much effort has been put on the efficient use of energy [3]. Batteries should be replaced and recharged manually at the field. However, in some situations it is impossible to recharge them because nodes may be deployed in an inaccessible environment. Moreover, in large scale sensor networks the number of nodes can be very high. In many cases a lifetime of several months, or even years, may be required. Because of environmental risks and cost of operation associated with batteries, renewable energy sources need to be used to power remote sensors. Sensors are deployed in remote locations for aquaculture monitoring. One of the challenges of operating sensors in remote locations is the lifetime of the sensors. This is limited by the power source they are connected to. The power source becomes more critical when the network becomes dense with many sensor nodes. The power source also limits reliability.

The ultimate goal of this research is to achieve a perpetually powered system without a necessary periodical maintenance for battery replacement or recharging. Wireless sensor networks (WSNs) for outdoor environmental monitoring are a class of systems where exploiting alternative power sources could increase the lifetime of the nodes considerably. Energy harvesting techniques can solve the problem by supplying and converting energy from the surrounding environment and refill an energy buffer formed by a battery stack [4].

Environmental energy harvesting, in particular solar based, has emerged as a viable technique to supplement battery supplies. However, designing an efficient solar harvesting system to realize the potential benefits of energy harvesting requires an in-depth understanding of several factors. For example, solar energy supply is highly time varying and may not always be sufficient to power the embedded system. Harvesting components, such as solar panels, and energy storage elements, such as batteries or ultracapacitors, have different voltage-current characteristics, which must be matched to each other as well as the energy requirements of the system to maximize harvesting efficiency. Further, battery non-idealities such as self-discharge and round trip efficiency, directly affect energy usage and storage decisions [5, 6].

The issue of power consumption has been widely studied for wireless sensor networks in general. In our previous work [7], we developed and deployed low cost short-range modules of wireless sensor network based on ZigBee standard and virtual instruments technology in order to monitor and control an aquaculture system in real time. What is special about deployments in aquaculture is that batteries cannot be replaced easily. Most of the time, the fishponds sites are located remotely far from the distribution network to power aerators. Even in cases where power might be available, the cost and difficulty of wiring to the existing power mains many times proves to be prohibitive.

In this paper, a solar oxygenation system to power the remote sensor nodes for water quality detection and aerators for aquaculture oxygenation was developed. We replaced node batteries with solar rechargeable batteries and implemented the solar oxygenation system for water aeration. The overall system cost can be reduced using high efficiency power conditioners which, in addition, are designed to extract the maximum possible power from the PV arrays under different operating conditions (maximum power point tracking (MPPT)).

The contributions of this paper include firstly, we discuss the desired features of such a solar harvesting module, and the services it should provide to the rest of the system to enable harvesting aware power management. Secondly, we illustrate how such harvesting aware operation can further improve system lifetime compared to state-of-the-art battery aware power management. Lastly, we present the design, implementation, and performance evaluation of our system deployed in real life environment. Our experimental results demonstrate the feasibility of self-sustained operation of outdoor sensor networks using solar energy harvesting. Solar energy conversion and battery energy storage can provide enough electricity for the experimental systems to power sensor nodes and drive the submersible pump continuously and increase oxygen of fishponds efficiently.

2. Related Works

While harvesting technology provides the ability to extract energy from the environment, it must be efficiently integrated into an embedded system to translate that harvested energy into increased performance and system lifetime [6]. Recently, several researchers have become interested in applying solar energy to wireless sensor networks. In particular, references [8, 9, 10] presented the hardware design principles for long-term solar-powered wireless sensor networks. A water circulation purifying device technology was designed by [11]. The device completely adopts the solar and wind energy as power for landscape water body purification. Further, [12] described a systematic approach to building micro-solar power subsystems for wireless sensor nodes.

Reference [13] developed an aerated water treatment system powered by photovoltaic/wind energy. The system may improve treated water quality. A water quality monitoring system using WSN technology and powered by solar panel in order to monitor water quality in different field sites and in real-time was presented by [14]. A novel system architecture constituted by several distributed sensor nodes and a prototype system using one node powered by solar cell and WSN technology was designed and implemented.

The optimization of energy generation in a photovoltaic (PV) system is necessary to let the PV cells operate at the maximum power point (MPP) corresponding to the maximum efficiency. Since the MPP varies, based on the irradiation and cell temperature, appropriate algorithms must be utilized to track the MPP. Different MPPT algorithms, each with its own specific performance, have been proposed in the literature [14]. An approach to determine the maximum power point (MPP) based on measurements of the open-circuit voltage of the PV modules and a nonlinear expression for the optimal operating voltage based on open-circuit voltage was proposed by [15]. The approach is a combination of the nonlinear and perturbation and observation (P&O) methods. Reference [16] presented a maximum power point tracking approach for a photovoltaic system using the dividing rectangles algorithm. The approach overcomes some weaknesses of the existing methods such as the perturb and observe method as it is capable of searching for global maximum. Furthermore, [17] suggested MPPT method with a simple algorithm based on use of a short-current pulse of the PV to determine an optimum operating current where the maximum output power can be obtained and it completely differs from conventional hill-climbing-based methods. In the proposed system, the optimum operating current is instantaneously determined simply by taking a product of the short-current pulse amplitude and a parameter k because the optimum operating current is exactly proportional to the short current under various conditions of illuminance and temperature. Moreover, [18] proposed two extended MPPT algorithms: Perturb and Observe and Incremental Conductance. In addition, [19] assessed the performance of MPP trackers due to the complexity and extensive measurement equipment by determining the actual impact of non-ideal, irregular conditions on MPPTs and developed solutions for improved performance. In total 13 MPPTs integrated in state-of-the-art PV inverters were tested with I/V curves measured at a real, shaded PV array. A perturb and observe (P&O) method was presented by [20]. This method is widely used because of its low-cost and ease of implementation. The method has a faster dynamics and improved stability compared to the traditional P&O. A scavenger that exploits miniaturized photovoltaic modules to perform automatic maximum power point tracking at a minimum energy cost was presented by [4]. The system adjusts dynamically to the light intensity variations [21]. Other researchers presented the performance of the MPPT method [22, 23].

In energy harvesting WSNs, in order to enable a node to work perpetually (until its hardware is worn out), the energy consumption rate of the node should not be higher than the energy recharge rate [8, 24, 25, 26, 27, 28]. Hence, the energy consumption should be treated using techniques specifically developed for harvesters in order to give time to the nodes to recharge themselves.

However, majority of previous research, including the works mentioned above, have focused only on node-level design, addressing topics such as hardware architectures and system analysis. The issues of powering actuators such as aerator pumps haven't been considered earlier. Therefore, we require finding a solution that manages and balances the variable energy in energy-harvesting nodes. Although there are many routing and management algorithms for improving energy in WSNs, most of them did not mention energy harvesting capabilities and error control mechanisms. Since providing the reliable communication is an important issue in WSNs, we have investigated a method to balance energy and improve the reliability as well.

3. Materials and Methods

3.1 Photovoltaic Arrays

The basic construction of PV panels is based on the PV cell, which are often connected together and encapsulated in one module. The module includes a sheet of glass on the sun side to allow light to penetrate while still protecting the semiconductor cells from damage. The cells within a module are normally connected in series to increase the overall voltage of the module. To prevent current flow from a producing cell into a dead or shaded cell, many PV modules utilize bypass diodes, allowing at least partial power output in shade. To prevent electricity from flowing back into the solar module, a blocking diode is commonly used between the module output and its target input.

While a wide diversity of harvesting techniques are now achievable, solar energy harvesting by photo-voltaic conversion contributes the highest power density making it the preferred method to power systems that exhaust less energy using a fairly miniature harvesting module. The principle of power generation using solar cells is based on the photovoltaic effect of semiconductors. Solar cells are made up of ptype and n-type semiconductors. When a solar cell is exposed to sunlight, the photons of the sunlight penetrate the semiconductor and are absorbed. The absorbed photon energy frees electron hole pairs. The energy of one photon is sufficient to free one negatively charged electron and one positively charged hole. The free electrons move to the n-type semiconductor, while the positively charged holes move to the ptype semiconductor [29]. This polarization of n-type and p-type semiconductors generates voltage. When the n- and p-sides are connected through a load, the electrons flow from the negative end to the positive end. At the positive end, the electrons combine with the holes. The flow of electrons generates electric current. A non-reflecting coating is used to reduce the loss of energy due to reflection from the surfaces of the solar cells [30].

The purpose of a solar harvesting system is to transmit energy from the PV cells to the batteries as efficiently as possible, imitate the optimal charging characteristics of the batteries for utmost period, avoid battery overcharge and undercharge, diminish or remove reverse discharge current when the solar cells are not working and to give stable, low-noise power to the sensor nodes and DC submersible pumps. The utilization of the MPPT in stand-alone systems is normally done by the series connection of a DC/DC converter between the PV array and the rechargeable battery in order to get the maximum power of the PV array. In as much as that in the series connection, the DC/DC converter processes all power generated making the total efficiency of the PV system dependent on the efficiency of this series DC/DC converter.

3.2 MPPT System Design

This section describes the solar energy-harvesting module developed in order to provide enough energy to power the sensor nodes and DC submersible aerator pump perpetually without human intervention. The first step to design the appropriate harvesting system consists of the evaluation of the system's energy requirements. The system uses solar cells as its main power supply. At the same time, it will supply power to the system and charge the storage batteries. AVR ATMEGA8 is used as the main control chip realizing the maximum power output of the solar cells though tracking the maximum power point algorithm. The microcontroller measures the solar cell voltage. As the light intensity decreases, the solar cell voltage will drop and switch to storage battery power supply when it is below battery voltage. Otherwise, the voltage will rise and the power supply will automatically switch to solar cells power supply. If the voltage reaches a threshold value, the system will power the DC submersible pump and sensor nodes as well as charging the batteries. The system includes over charging and undercharging monitoring of the battery storage mechanism. For example, in some situations (like at night) when the available energy is very low, the battery cannot be recharged and the energy consumption of transmitting data reduces the amount of battery charge.

On the other hand, at other times (like at noon) the energy consumption of data transmission is compensated at the earliest possible opportunity. Although a high amount of environmental energy is available in some intervals, the stored energy cannot exceed the battery capacity since it is limited. The schematic design of the MPPT system is shown in Figure 1.

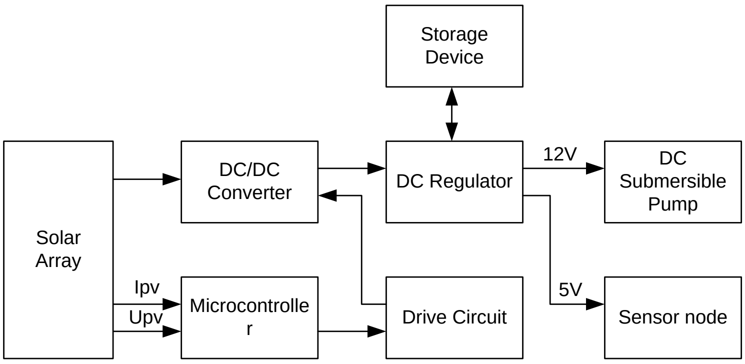

Fig 1: Schematic design of the MPPT system

3.3 Energy Measurement

The design principle of the solar cell is to meet the daily electricity demand for the sensor nodes and submersible pumps load under the average weather condition i.e., a full charge must be reached under the condition of weakest light intensity. While the design principle of the storage battery is to guarantee the normal working of the load when light intensity is below average.

According to [31, 32], the calculation method of solar power parameters is as given in equations (1-5).

$$Q_{Array} = \frac{w}{v_{Battery-Array \times \varepsilon\delta}} \times \beta \times T \tag{1}$$

$$N_{PV-series} = \frac{v_{load}}{v_{PV-cell}} \tag{2}$$

$$N_{PV-parallel} = \frac{I_{PV-Array}}{I_{PV-cell \times \gamma}} \tag{3}$$

$$N_{Battery-series} = \frac{v_{Battery-Array}}{V_{Battery}} \tag{4}$$

$$N_{Battery-parallel} = \frac{Q_{Array}}{Q_{Battery}} \tag{5}$$

The notations expressed in the Equations (1-5) are described in Table 1. The output current and voltage of solar cell arrays are measured by the high voltage power monitor LTC4151. The output power of solar cells changes with the variation of environment and it is hard to track its maximum power point. Hence, we used 12-bit ADC LTC4151 to measure the current at high voltage side and the input voltage continuously thereby providing power for the system timely. The driver circuit adopts the chip TC4422. Its input side is connected with the PWM output side of ATMEGA8 microcontroller and its output side in series with a resistor valued 10Ω is connected with the grid electrode of MOSFET. The DC regulator provides stable 12 V to power DC submersible pumps and 5 V to power sensor nodes. The solar harvesting circuit establish operation proximal maximal power point by terminating the solar panel to a stable voltage. Table 2 depicts the PV, battery and converter specifications used for this experiment.

TABLE 1. NOTATIONS

Symbol	Quantity	SI Units
$I_{PV-Array}$	the total required current of PV arrays	[A]
v_{load}	the load working voltage	[V]
t_{peak}	the peak sunshine hours, its value is on the base of different weather conditions	[h]
β	the design margin, its value is according to experience and security demands	[dimensionless]
Q_{Array}	the necessary storage battery capacity	[Ah]
$v_{Battery-Array}$ ε	the voltage of storage battery	[V]
	the maximum depth of discharge of storage battery, the values of deep and shallow circulation battery are 80% and 50% respectively	[%]
δ	The correction factor of battery temperature	[t]
T	the sequential days	[d]
$N_{PV-series}$	the number of PV arrays in series	[n]
$N_{PV-parallel}$	the number of PV arrays in parallel	[n]
$N_{Battery-series}$	the number of storage batteries in series	[n]
$N_{Battery-parallel}$	the number of storage batteries in parallel	[n]
$v_{PV-cell}$	working voltage of PV cells	[V]
$I_{PV-cell}$	working current of PV cells	[A]
γ	the battery coulomb efficiency	[mg/C]
$v_{Battery}$	battery voltage	[V]
Q_{Array}	capacity	[Ah]

TABLE 2. PV, BATTERY AND CONVERTER SPECIFICATIONS

Category	Specifications	Purpose
The frequency of switchingtube, f_{sw}	80 kHz	
Input DC voltage $v_{in} \in [10V, 21V]$	its rated value: 17.4V	
Output DC voltage $V_{out} = 19V$	output current rating $I_{out} = 13.6A$	for powering DC submersible pump
Output DC voltage $V_{out} = 5V$	output current $I_{out} = 1.2A$	for powering sensor nodes and the inductive current works in the continuous conduction mode(CCM)

STP130-12/Tb solar cells	sunshine intensity is 1000 w/m^2 when environment temperature is 25°C; open circuit voltage is 22V; short circuit current is 16.18A maximum power point output voltage is 17.4V; maximum power point output current is 14.94A)	the total area is 2.5 m^2
storage battery, lead-acid batteries	output voltage is 12V	capacity is 150Ah
DC submersible pump	rated input voltage is 12V; rated input current is 5.4A; rated input power is 64.8W; rated output power is 45W	the pump head is 4m
DC/DC convertor	inductance is 330 μH, input capacity is 10 $\mu F/50V$, coupling capacity is 47 $\mu F/50V$	output capacity is 330 $\mu F/50V$

3.4 System Software

The architecture consists of a pool of modules which contains all the possible modules needed by the sensor nodes and submersible aerator pumps for a particular application. The main program includes voltage and current detection module and maximum power point tracking module. Main system program controls the tracking of maximum power point according to real-time detecting voltage and current of solar cell arrays. In order to prevent measurement error of the chip that may lead to subsequent wrong logical judgments, we set the threshold value of voltage and current. The system will compare the measured with threshold values and measure when the former exceeds the latter. The tracking control algorithm of the maximum power point uses incremental conductance method by changing the DC/DC converter output voltage while increasing or decreasing the PWM duty cycle to achieve maximum power point tracking [17, 33]. During compile-time, software modules are compiled and loaded into the flash memory of the microcontroller and organized memory sectors of the ROM, such that every module is given a set of default features and identifiers such as energy stamp, priority level, execution order and memory space.

3.5 System Software

Two cells were separately installed in two adjacent fishponds in Dar es Salaam, Kigamboni district at Ungindoni Aquaculture farm in order to assess the proper operation of the system and evaluate the feasibility. The experiment uses two STP130-12/Tb solar cells made by Guangzhou Fujie Electronic Technology Co., Ltd. For the storage battery, we used three lead-acid batteries in parallel made by Guangzhou Dahua Storage Battery co., LTD. A 48 V, DC submersible pump is used which is made in Xuzhou Taifeng Submersible Pump Factory. It works 8 hours a day and can normally work continuously for three rainy days. The Switching tube uses IRFZ48N MOSFET made by American International Rectifier. Output diode uses SB 140 made by American General Semiconductor.

This system uses solar battery to drive the DC submersible pump and floating settings, trumpet-shaped tubular construction to discharge the water in the bottom of the pond into the surface in the shape of radiation. This would destroy the anaerobic layer and the thermocline and transmit substance in maximum mass transfer force. More oxygen could be brought to the deep water after entering water surface. It can prevent harmful algae blooms, destroy the structure of bloom, keep the indigenous flora alive, improve the water quality of decomposition of organic waste and improve dissolving oxygen amount in an efficient and low-cost way. Figure 2 shows the system structural drawing and experimental set. The compressed air normally starts to roam approaching the surface of the water immediately upon discharged at the basement of a fishpond. As air ascend the water column, the pressure neighboring the droplets gradually contracts leading the droplets to expand in magnitude. The compressed air sacks oxygen-depleted water from the water base, oxygenates it and moves it to the top [24]. This operation conserves fish, aquatic organisms and useful bacteria from death by tearing down stratified waters while rising dissolved oxygen concentrations. Low dissolved oxygen concentration and very stratified waters can indicate depraved fishponds where mild, oxygen-rich water is suspended on top and cool oxygen-depleted bottom waters.

Fortunately, degraded fishponds can conveniently be complemented with the use of DC submersible aeration system developed in this paper. Fishpond aeration acts to add dissolved oxygen concentration while removing stratified waters. Aerobic bacteria begin to immigrate in deeper water, where they swiftly start to digest compiled sediment and enhance water quality.

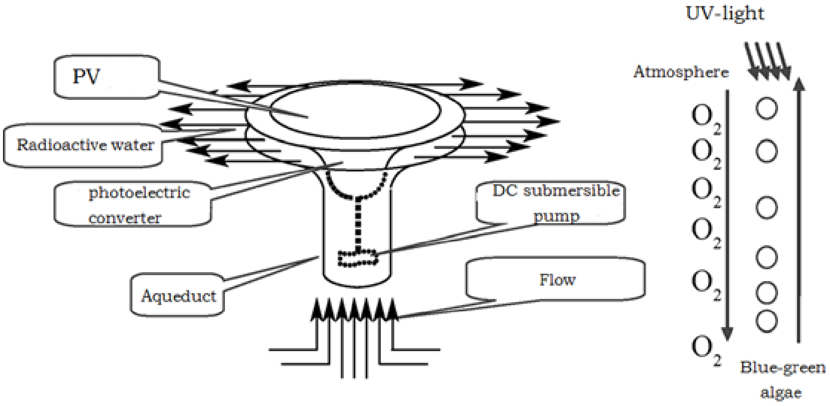

Fig 2: Submersible pump structural diagram

4. Results and Discussion

The main system transfers MPPT data to remote control through the RF module, and the remote control will choose to enter the data displays item and transfer data such as voltage and power to the system via serial port. The power-time variation data is shown in Figure 3. The figure reveals that the system output generally maintained at 288.12 W, whereas DC submersible pump is capable of using 64.8 W. This makes possible for our solar system to drive up to 4 DC submersible pumps increasing its robustness. The system output voltage was maintained at 18.5V as shown in Figure 4. When observing the battery behavior through the corresponding message fields, we found that battery charge before transmission was around 100%, even on days with scarce solar radiation. However, battery charge has not been under 95% in any of the measurements obtained as shown in Figure 5. Battery measurements of both sensor nodes deployed turned out to be nearly identical. Our experimental results had shown that sensor nodes and DC submersible aerator pumps mainly uses the energy stored in the storage batteries when there is no enough light intensity (at night or on cloudy days). This solution increases the flexibility in the design of the network architectures. Experimentally, we have also tested that rechargeable batteries are enough to extend the sensor nodes operational life with charge cycles (in sunny conditions) and discharge cycles (when it is used as power supply source). However, in scenarios with an occasional use, charge and discharge cycles must also be forced in order to take care of the battery (avoiding its memory effect). We take it into account in our energy module design. The dissolved oxygen variations before and after the experiments is shown in Figure 6. The result reveals that the systems performance was stable with sensor nodes and DC submersible pump aeration. During our experiment, the dissolved oxygen concentration was not below 5 mg/L which is the optimum condition for aquatic animals to survive provided that other environmental parameters are within optimum range. It can further be seen from Figure 6 that before the experiment with solar powered sensor nodes, dissolved oxygen increased during the day due to photosynthesis and decreased at night when respiration happens. This shows that our system is reliable and useful to power and oxygenate fishponds thus avoiding catastrophic losses to the fish farmers. The load curve, generated power with power from storage batteries-time variation is shown in Figure 7. The output power from PV arrays increases during the day and stays low at night. The storage battery supports system power when the sunlight is low. However, the load curve was stable with the sensor nodes able to function properly during our experiment. The sensor nodes were designed as a low power easily adaptable in harsh environments. For all nodes we continuously logged data from the solar panel and node batteries.

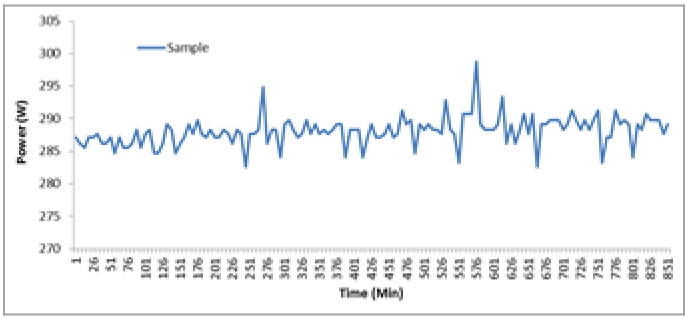

Fig 3: The power-time variation

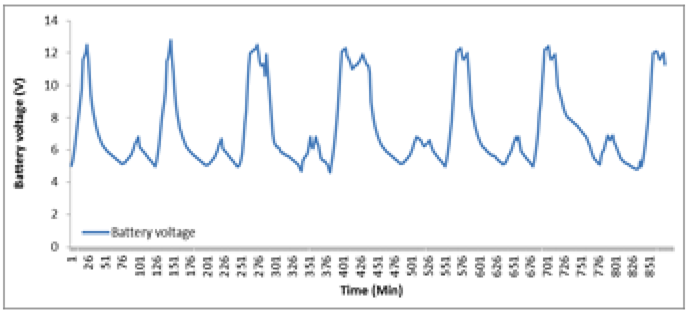

Fig 4: The battery voltage-time variation

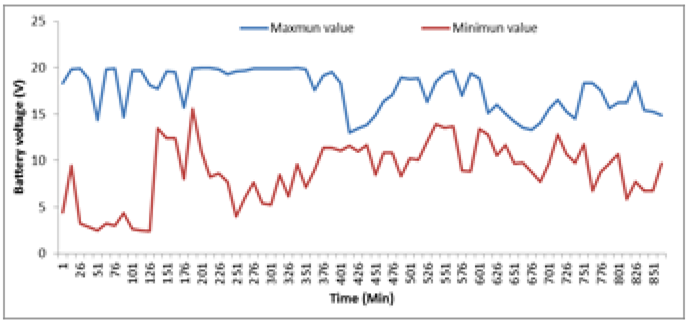

Fig 5: The minimum and maximum battery voltage-time variation

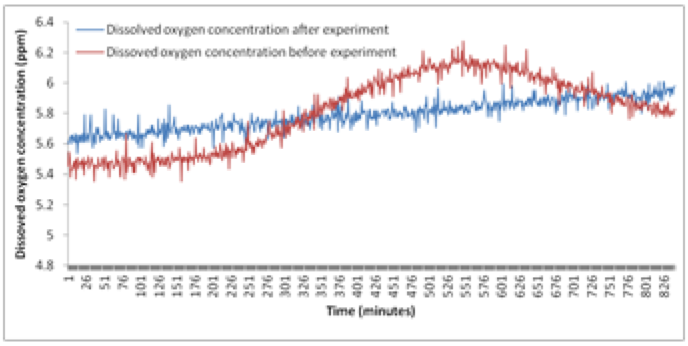

Fig 6: The dissolved oxygen-time variation before and after experiments

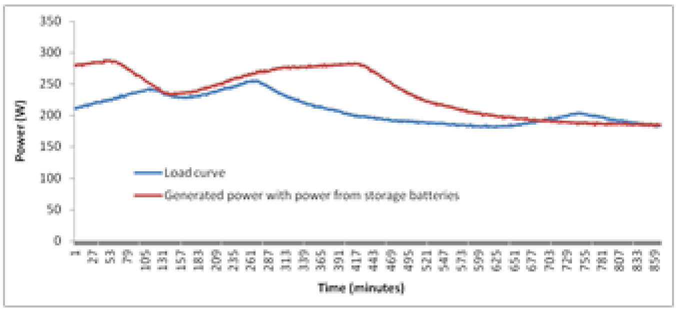

Fig 7: The load curve, generated power with power from storage batteries-time variation

Regression analysis of the rechargeable battery performance experimental data with a linear fit gave a determination coefficient, =0.9919, showing that a close relation between the values exists. Part of the power is consumed by the sensors, microcontroller ATmega8, the communication module and the aeration pump as actuator. In our case, energy consumption is reduced by using low power hardware (sensors, microcontrollers, radio chips) for implementing sensor nodes that consume typically significantly less energy. The hardware and software presented here are designed specifically to address the needs of WSNs namely efficiency power consumption, low cost and scalability that integrates detection, processing and storage.

These battery voltages while not a perfect indicator of the capacity remaining in the batteries; can give a good idea about the performance of the harvesting system. Note that the battery voltage should not be measured during the charging period; while charging a battery, the battery voltage reading doesn't represent actual battery voltage. The battery voltages were recorded over an extended time period to assess the system's suitability for long-term aquaculture applications.

The aquaculture test results were in the same way satisfactory as reported in our previous work [7]. The dissolved oxygen level was constant at night sustained by aerator pumps. However, during the day most of the time the aerator pumps were idle, due to enough dissolved oxygen level depending on daily weather. In some cases, especially on cloudy days, even during the day the ponds dissolved oxygen level had to be sustained by aerator pumps. The relays were working properly at each node. Remote actuation of water valve and aerator pump with the wireless network was successfully demonstrated indicating that the software and firmware were properly functioning. They were automatically switching on/off whenever the parameters were outside preset range.

5. Conclusions

The results presented in this paper demonstrate how effective the solar energy harvesting system is at increasing the life time of WSNs. The solar panel selection, the hardware modifications, and the software modifications all culminated to create a successful energy harvesting system that was used on powering sensor nodes and submersible aeration pump in aquaculture monitoring and control system.

The energy harvesting system developed for this research has been experimentally verified and can increase the lifetime of an entire network to reach that of its individual hardware components. Compared with traditional pond aeration manner, the solar energy aerator system makes the full use of clean energy from the sun and greatly saves the energy cost. It provides a new method for the study of strengthening the polluted water self-purification capacity. We realized MPPT algorithm that could switch power source according to light conditions, then realized the unification of energy storage and power supply, and ensured the continuous stable operation.

The future research work would be enhancing submersible pumps capability by designing autonomous movable floating aerator device for even and wide aeration of the fishponds. Further, the sensor nodes should be equipped with GSM device for self-reporting to the user in case of malfunction.

Acknowledgment

The author would like to thank members of the Ungindoni Aquaculture farm for assistance in setting up the experiments and help during data collection and members of Computer Studies department for their sincere help and advice which led to the completion of this paper.

References

[1] Beeby, S., & White, N. (2010). Energy harvesting for autonomous systems: Artech House.

[2] Jalali, F., Khodadoustan, S., & Ejlali, A. (2012). Cooperative hybrid ARQ in solar powered wireless sensor networks. Microelectronics Reliability, 52(12), 3043-3052.

[3] Lalitha, A., Mondal, S., Kumar, S., & Sharma, V. (2013). Power-optimal scheduling for a green base station with delay constraints. Paper presented at the Communications (NCC), 2013 National Conference on.

[4] Brunelli, D., Benini, L., Moser, C., & Thiele, L. (2008). An efficient solar energy harvester for wireless sensor nodes. Paper presented at the Proceedings of the conference on Design, automation and test in Europe.

[5] Mouse, E. (2006). Mouser Electronics, Energy Harvesting Technology. Retrieved from http://in.mouser.com/applications/energy_harvesting_solar/, a.

[6] Raghunathan, V., Kansal, A., Hsu, J., Friedman, J., & Srivastava, M. (2005). Design considerations for solar energy harvesting wireless embedded systems. Paper presented at the Proceedings of the 4th international symposium on Information processing in sensor networks.

[7] Simbeye, D. S., Zhao, J., & Yang, S. (2014). Design and deployment of wireless sensor networks for aquaculture monitoring and control based on virtual instruments. Computers and Electronics in Agriculture, 102, 31-42.

[8] Basagni, S., Conti, M., Giordano, S., & Stojmenovic, I. (2013). Mobile Ad Hoc networking: the cutting edge directions (Vol. 35): John Wiley & Sons.

[9] Corke, P., Valencia, P., Sikka, P., Wark, T., & Overs, L. (2007). Long-duration solar-powered wireless sensor networks. Paper presented at the Proceedings of the 4th workshop on Embedded networked sensors.

[10] Dondi, D., Bertacchini, A., Larcher, L., Pavan, P., Brunelli, D., & Benini, L. (2008). A solar energy harvesting circuit for low power applications. Paper presented at the Sustainable Energy Technologies, 2008. ICSET 2008. IEEE International Conference on.

[11] Zhang, S.-Y., Li, G., Wu, H.-B., Liu, X.-G., Yao, Y.-H., Tao, L., et al. (2011). An integrated recirculating aquaculture system (RAS) for land-based fish farming: The effects on water quality and fish production. aquacultural Engineering, 45(3), 93-102.

[12] Taneja, J., Jeong, J., & Culler, D. (2008). Design, modeling, and capacity planning for micro-solar power sensor networks. Paper presented at the Proceedings of the 7th international conference on Information processing in sensor networks.

[13] HU, M.-c., ZHANG, Y.-c., WANG, W.-l., TANG, X.-y., & WANG, J.-h. (2010). Wind and Solar Energy Powered Water Purification System of Aerobic Biological Contact Oxidation. Journal of Ecology and Rural Environment, S1

[14] Yue, R., & Ying, T. (2011). A water quality monitoring system based on wireless sensor network & solar power supply. Paper presented at the Cyber Technology in Automation, Control, and Intelligent Systems (CYBER), 2011 IEEE International Conference on.

[15] Tafticht, T., Agbossou, K., Doumbia, M., & Cheriti, A. (2008). An improved maximum power point tracking method for photovoltaic systems. Renewable energy, 33(7), 1508-1516.

[16] Nguyen, T.L. and Low, K.S., 2010. A global maximum power point tracking scheme employing DIRECT search algorithm for photovoltaic systems. IEEE transactions on Industrial Electronics, 57(10), pp.3456-3467.

[17] Noguchi, T., Togashi, S., & Nakamoto, R. (2002). Short-current pulse-based maximum-power-point tracking method for multiple photovoltaic-and-converter module system. IEEE Transactions on Industrial Electronics, 49(1), 217-223.

[18] Houssamo, I., Locment, F., & Sechilariu, M. (2010). Maximum power tracking for photovoltaic power system: Development and experimental comparison of two algorithms. Renewable energy, 35(10), 2381-2387.

[19] Bruendlinger, R., Bletterie, B., Milde, M., & Oldenkamp, H. (2006). Maximum power point tracking performance under partially shaded PV array conditions. Proc. 21st EUPVSEC, 2157-2160.

[20] Piegari, L., & Rizzo, R. (2010). Adaptive perturb and observe algorithm for photovoltaic maximum power point tracking. IET Renewable Power Generation, 4(4), 317-328.

[21] Qian, H., Sun, P., & Rong, Y. (2012). Design proposal of self-powered WSN node for battle field surveillance. Energy Procedia, 16, 753-757.

[22] Ji, Y.-H., Jung, D.-Y., Kim, J.-G., Kim, J.-H., Lee, T.-W., & Won, C.-Y. (2011). A real maximum power point tracking method for mismatching compensation in PV array under partially shaded conditions. IEEE Transactions on power electronics, 26(4), 1001-1009.

[23] Mei, Q., Shan, M., Liu, L., & Guerrero, J. M. (2011). A novel improved variable step-size incremental-resistance MPPT method for PV systems. IEEE Transactions on Industrial Electronics, 58(6), 2427-2434.

[24] Chen, W., Andreopoulos, Y., Wassell, I. J., & Rodrigues, M. R. (2013). Towards energy neutrality in energy harvesting wireless sensor networks: A case for distributed compressive sensing? Paper presented at the Global Communications Conference (GLOBECOM), 2013 IEEE.

[25] La Porta, T., Petrioli, C., & Spenza, D. (2011). Sensor-mission assignment in wireless sensor networks with energy harvesting. Paper presented at the Sensor, Mesh and Ad Hoc Communications and Networks (SECON), 2011 8th Annual IEEE Communications Society Conference on.

[26] Magno, M., Brunelli, D., Zappi, P., & Benini, L. (2010). Energy efficient cooperative multimodal ambient monitoring. Paper presented at the European Conference on Smart Sensing and Context.

[27] Nishimoto, H., Kawahara, Y., & Asami, T. (2010). Prototype implementation of ambient RF energy harvesting wireless sensor networks. Paper presented at the Sensors, 2010 IEEE.

[28] Zungeru, A. M., Ang, L.-M., Prabaharan, S., & Seng, K. P. (2012). Radio frequency energy harvesting and management for wireless sensor networks. Green mobile devices and networks: Energy optimization and scavenging techniques, 341-368.

[29] Johnson, R. D., & Holbrow, C. (1977). Space Settlements. A Design Study. NASA, Washington, SP-413.

[30] Dewan, A., Ay, S. U., Karim, M. N., & Beyenal, H. (2014). Alternative power sources for remote sensors: A review. Journal of Power Sources, 245, 129-143.

[31] You, G., Yang, S., Li, J., Hou, Y., Wang, X., Nan, Z., et al. (2012). Solar oxygenation system for aquaculture and running effect. Transactions of the Chinese Society of Agricultural Engineering, 28(13), 191-198.

[32] Yang, H., Zhou, W., Lu, L., & Fang, Z. (2008). Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm. Solar energy, 82(4), 354-367.

[33] Manganiello, P., Ricco, M., Monmasson, E., Petrone, G., & Spagnuolo, G. (2013). On-line optimization of the P&O MPPT method by means of the system identification. Paper presented at the Industrial Electronics Society, IECON 2013-39th Annual Conference of the IEEE.

Author' Biography

Daudi S. Simbeye received the B. E. degree in electronics and microelectronics from Moscow Power Engineering Institute (Technical University) and the M. E. degree in design and technology in electrical engineering from Southern Federal University-Taganrog Institute of Technology, Russia, in 2006 and 2008 respectively and the Ph.D degree in light industry technology and engineering at Tianjin University of Science and Technology, China in 2014. From 2008 to 2014, He was an assistant lecturer in the department of computer studies at Dar es Salaam Institute of Technology, Tanzania. Since 2015 to date, he is a Lecturer in the department of computer studies at Dar es Salaam Institute of Technology, Tanzania. His areas of interest include information detection and intelligent technology, embedded systems and Wireless sensor networks.