DESIGN OF A GREEN IOT BASED WATER MONITORING SYSTEM FOR METROPOLITAN CITY.

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Abstract— **Water is essential for life. However, waste is a major problem in the world. Although, several research work have proposed the use of IoT as a solution to curb waste and achieve effective billing. However, in developing countries like Nigeria, the application of such technology is challenging since power or energy supply is often times erratic in nature. Taking Tunga Minna, Niger state Nigeria as a case study, it is observed that the rate of power outage is high. This will however, result to large loss of water consumption data that is supposed to be uploaded to the cloud via IoT platform. To reduce the level of outage, this study presents the design of a green IoT based water monitoring system for metropolitan area. The purpose of the design is to ensure minimum probability of outage. The scope of the design is limited to the hardware design. At the end, it is expected that a design with low probability of outage is achieved.**

Keywords—IoT, probability, outage, green, water monitoring, system.

I. Introduction

The importance of water cannot be overemphasized as it is widely accepted as a necessity for life [1]–[3]. Being about 70% to 71% of the earth mass [4], [5], 2.5% to 3.4% of it, is fresh water [4], [6] of which, only 0.07% to 0.08% is accessible for consumption [5], [6]. As a result, efforts have been made globally by water utility managers to ensure efficient distribution of this scarce commodity [4],[7]-[8] via a dynamic network of relevant components called water distribution network(WDN). Maintaining such services remains challenging [7] as over 348 million people still experiences water scarcity [12]. According to the World Health Organization (WHO), 1.1billion people have no access to portable water [13]. This can be blamed on the tripled demand for water since 1950 [8] which results from the rapid growth of population despite the progressive reduction in the rate of rainfall due to climate change [6], [9]. Furthermore, it is observed that poor management on the part of the consumers [6] and poor fund generation by utility managers plays a major role. According to [4], large portion of the fresh water distributed flows back to the ocean unused. This gives a clear picture of waste by opening taps when not needed and portraying careless attitude towards leaking pipes in the WDN possibly because of lack of funds to mend them. This however, tends to validates a survey conducted by World Bank, estimating real loss of water of about 32.7billion m^3 per year. Furthermore, it was observed that both real and apparent loss of water results to the loss of 14.6 billion USD per year [10]. To minimize the losses, it is important for individuals and utility to ascend a level of responsibility which can be achieved if there are effective medium to monitor and quantify the amount of water consumed or lost [11]. This however can only be achieved via the use of Internet of Things.

Internet of Things (IoT) is a paradigm that allows everything and everyone to communicate using the internet platform [12], [13]. These things which may includes mobile computing devices, sensors, actuators and other objects, must be readable, locatable, recognizable, addressable and interconnected through the internet via a stipulated protocol called the internet protocol (IP) [14]–[16]. Using this in a WDN will improve operational services in water distribution. However, despite the positive effect experienced in advanced nation in the deployment of this technology in the monitoring of the water consumed, its application is rather challenging in developing nations like Nigeria especially in Tunga Minna Niger state where power is available between the hours of 9am to 12pm and the hours of 9pm to 12 mid night because of load shedding. This will however, increase the probability of outage which results in large loss of data aside the few times when downtime is experienced within the wireless network. To solve this problem, this study presents the design of a Green IoT based water monitoring system for a metropolitan area. The objective of the study is to

1. Design a system that can measure the water consumed by each home in real time
2. Design a subsystem that uses natural means to compensate for power when not available so as to reduce the probability of outage.

However, it is important to note that the scope of this presentation is restricted to hardware design

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II. Review of related works

The management of water is key since fresh water which is supplied after being treated via the WDN is often scarce [4], [5], [16]. However, to curb waste as described by [4], it is important that water management should be consumer inclusive. To achieve this, effective monitoring via the use of constrain devices is needed. This will also aid consumption awareness, leak detection, demand forecasting and variable water pricing [17] which will help to generate revenue through billing for the expansion and maintenance of the network. According to [27], there are basically two methods of monitoring and managing water. The first is the Approach model base method. This involves the search of new source of fresh water which is often demanding, difficult and exhaustive. The second method is the measurement based method. This involves the use of constrained devices such as water meters to monitor demand of water consumed which can be further translated to bills for consumers. Of these two approaches, the latter is most considered by researchers. As a result, water meters have evolved over the years so as to aid the periodic reading of water consumed and ensure efficient and transparent billing [7].

Over the years, there have been manual approaches used to measure the quantity of water consumed. Authors in [11], [23], [24], mentioned how utility officers in some countries such as India will have to go around town to get data from mechanical based water meters installed in homes. These data generated may be considered discontinuous and may be full of errors as a result of fatigue while gathering the data or deliberate manipulation. Furthermore, according to the study, there may be instances when data cannot be collected because some meters may be inaccessible to some utility officers. For this reason, the application of real time technology is needed.

In a city called Antalya in Turkey, a study by [15] indicated the need for real time monitoring in water management. In the study which focused on monitoring the quality of water, real time monitoring via the use of real time Supervisory Control and Data Acquisition (SCADA) helped to improve operations by buzzing alarms when parameters measured by constrained devices go beyond desired standard measurements. Furthermore, the research focuses on making WDN safe as intended by [25] by communicating the quality status of the water to the consumers wirelessly via the use of expensive IBM servers, UHF mas radios, repeaters and a Motorola gateway.

Similarly, water quality was monitored by [4] in a smart water grid achieved via the use of Low Power Wide Area Network (LPWAN) IoT technology. At the front end, the sensors used includes: oxidation reduction potential sensor, pH sensor, salinity sensor, flow rate sensor, water level sensor, turbidity sensor and temperature sensor. Long range (LoRa) transceiver was used with a LoRa gateway to transmit data to the Ericson cloud used. Also, an alert was sent via SMS when parameter measured is critical.

To increase the efficiency of water monitoring which will lead to efficient billing, [23] presented a design of a LoRa Technology based low cost water Meter reading system. The design was conceived so as to overcome the limitation of not able to access mechanical meters previously installed in India. With the use of LoRa, a wireless technology with low power consumption but longer range communication capabilities is proposed; Utility officers can stay around the area of operation and gather data from different meters in a geographical area without going close to the meter. Afterwards, the bills can be computed and sheared to customers. An advanced design was presented by [27] and [28]. Demand data set is gathered from different meters using the LoRa or Sigfox technology.

Authors in [29] presented the design of an intelligent Meter reading Technology based on Narrow Band (NB) IoT. In their work low cost STM32F103 controller was interfaced with OV7725 camera module. This was done to capture the reading on mechanical based water meters. Afterwards, image processing is done to extract the numbers on the counter. This was thereafter sent to the cloud via the use of narrow band IoT.

Authors in [30] present a design that employs a flow rate sensor to measure the water consumed by customers. Afterwards, the controller MSP430 was used to process the data and compute the billing and then display the unit consumed on a liquid crystal display (LCD). This same data and the billing are sent to a central data collection or the cloud system via the use of a WiFi module called ESP8266. To aid user inclusiveness, android application was designed to help customers to be able to see what is consumed and how bill is generated [18]. This however, is similar to the design presented by [31]. The water meter and android application developed retrieves consumption data on the meter. This data is then forwarded to utility for billing by the consumer.

Authors in [14] also presented an IoT approach for water monitoring and control. In the presentation, SCADA was suggested as a tool at the application layer. With a focus on the architecture that will aid IoT monitoring and control in the water sector, unique identification of things was tagged important. This is to aid localization of fault finding within a WDN. To achieve this, it was suggested that RFID technology will be a low cost solution.

To reduce waste of natural resources and financial resources, [32] presented a microcontroller based system for telemetry measurement of water consumption using IoT. To achieve this design, a flow meter was used to measure the consumption of water. Also, a controller with IEEE802.15.4 standard was used so as to aid communication to the cloud via Wi-Fi. Furthermore, visual display of consumed water was presented to the customers.

Authors in [5] also presented a paper that describes how IoT is used to manage water smartly in homes. The design which made used of ultrasonic sensor and turbidity sensor monitors the level of water in a tank and also how clean the water is. The data generated from the monitoring is sent to the cloud. Also, an alert is sent when the water is critically low so that the consumer could call tanker for supplies.

Authors in [20], with the intension to optimize intelligence in water management, proposed the use of IoT to aids real time monitoring of water distribution in Taiwan. Furthermore, cloud storage and big data analytics was used to add value to the work. With the proposed design, wasteful attitudes were checked.

All these contributions from previous work made contributions with the assumption that power supply is always available. None considered the peculiar situation of our location of study Tunga Minna Niger state Nigeria. Therefore, the contribution of this study will be useful for places having similar challenges like our case study.

III. METHOD

The section presents the method adopted for the design of the system. This includes hardware and software designs

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A. Hardware Requirement

The following hardware components is used to achieve the design of the system

- Flow sensor
- Battery
- Controller(NODEMCU)
- Wireless router
- Liquid crystal display (LCD)
- Solar panel
- Potentiometer
- Relay and driver

B. Software Requirement

To achieve the design of the system, Arduino IDE which is one of the software needed has to be configured so as to be able to burn the algorithm into the Nodemcu controller. Furthermore, for the purpose of presentation in this study, Fritzing was used to achieve the drawing of the design.

C. Hardware/System Achitecture

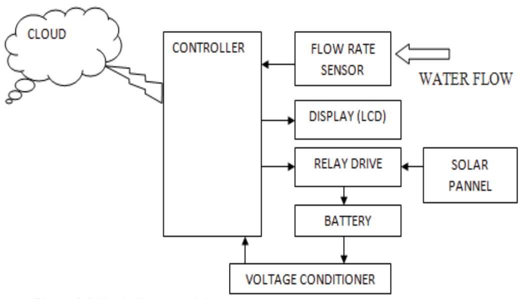

Figure 2. A diagram showing Hardware Architecture.

Figure 2 shows the various units which aids the design of the system and how they are interconnected. When water flows through the water flow sensor, pulses with respect to the volume of water measured is read by the controller. This then aids the displayed of volume consumed on the Liquid crystal display (LCD). This same information is sent to the cloud data base via the use of IP. However, since the intention is to make the system independent of public supply, the system is powered via a battery which is charged using a solar panel of 8V. To avoid over charging, a voltage conditioner helps to condition the battery voltage to voltages ranging from 0V to 2.5V. This fraction is fed into the analog pin of the controller. Furthermore, the system outputs logic that aids the charging of the battery by a 8V solar panel via the relay every three hours' interval. As it charges, if the voltage read by the controller is as high as 8.2V, the controller outputs a counter control logic that de energizes the relay, thereby terminating charging.

D. Controller

To achieve compactness, the controller to be used for this design should have TCP/IP protocol stack, analog to digital input, consume less power and must have medium of internet connection and digital inputs. However, due to these considerations, Node-mcu ESP8266, U1 as shown in Figure 4 is considered suitable for the design.

E. Power Supply

As recommended by the manufacturer, the controller (Node-mcu) can be powered with a 3.3V to 5V supply. Since the intention is to ensure that the system is independent of the public power supply which is erratic in nature. A battery with voltage higher than 5V is considered suitable for optimal design. To achieve this, two 3.7V lithium batteries as shown in Figure 4 were connected in series so as to achieve voltage higher than 5V. Furthermore, a 7805 voltage regulator IC1 as shown in the same Figure was used to achieve the maximum required voltage to power the controller.

F. Mathematical analysis of how much power is needed

One battery produce $3.7V\ 1600mAh$

Two batteries in series give the total voltage given as $Total\ voltage(\mathrm{V}_{battery}) = 2\times 3.7V = 7.4V\ 1600mAh$

To achieve longer periods of operation of the node, the following considerations were made:

- Maximum current consumed by the controller $(I_{\max(mcu)}) = 170nA$
- Maximum current consumed by the display $(I_{\max(LCD)}) = 2.5mA$.
- Maximum current consumed by the flow-rate sensor $(I_{\max(flowrate)}) = 1.5mA$
- Maximum current consumed by the relay $(I_{\max(relay)}) = 70mA$
- Maximum collector current consumed by the transistor A1015 $(I_{\max(transistor)}) = 0.15A$

- Current flowing through voltage conditioner $(I_{\max(vc)}) = \frac{V_{battery}}{R}$

Let $R = 100k\,\Omega$

$I_{\max(vc)} = 74\,\mu A$

Total current consumed by node is given as $I_{total} = I_{\max(mcu)} + I_{\max(LCD)} + I_{\max(flowrate)} + I_{\max(relay)}$

$+ I_{\max(transistor)} + I_{\max(vc)}$

$I_{total} = 0.161A$

Total power supplied by the battery

$P_{battery} = V_{battery} \times I_{battery}$

$P_{battery} = 7.4V \times 1600mAh = 11840mWh$

Total power consumed by the device is given as

$P_{consumed} = V_{reg} \times I_{total}$

$V_{reg} = 5V$

$P_{consumed} = 5 \times 0.161 = 0.805W$

The time to drain out the battery is

$$T_{drain} = \frac{P_{battery}}{P_{consumed}} = \frac{11.840}{0.805}$$

$T_{drain} = 14.7h$

This means it takes 14.7h to drain the battery out. However, it is intended that the system should not drain the battery to a voltage less than 5.5V before charging takes place. Therefore, the time it will take to drain the battery out if it retains charge of 5.5V is given as

$$\frac{5.5}{7.4} \times 14.7h = 11h = T_{drain(5.5)}$$

Therefore if fully charged, it will take $T_{drain-}T_{drain(5.5)}$ hours for the battery to drain to the level of minimum threshold (5.5V). It therefore takes 4hours to drain the battery to 5.5V. Since minimum of 12 hours is needed for night purpose, 4 pairs of this series connection are needed to achieve $4 \times 1600 = 6400$ which yields $4 \times 4hrs = 16hrs$ before the battery goes below 5.5V. This will be able to power the system all through the night when solar power is not available.

G. Flowrate Sensor

The sensor used for the design of the system as shown in Figure 4 is YF-S201. The sensor can operate within 4.5V to 18V DC. The sensor which can measure flow rate between 1 to 30 liters per minutes is connected such that the power pins are connected to Vcc and ground of the circuit, While, the point that generated the signal is connected to D2 of the controller. Figure 3 shows how it is set up. Its workability is hence governed by the equation below:

$$Q = vA \qquad (1)$$

Where Q is the flow rate

v is the velocity of the fluid

A is the cross sectional area of the pipe.

Equation (1) can be rewritten as

$$Q = \pi\left(\frac{D}{2}\right)^2 v \qquad (2)$$

Where $A = \pi(\frac{D}{2})^2$. To calculate for the volume of water consumed

$$volume = \left(\frac{Q \times T}{60\sec}\right) \text{m}^3 \qquad (3)$$

Where T is the time of sensing

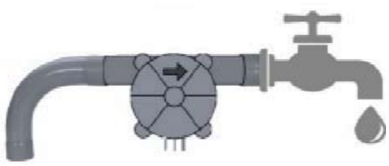

Figure 3 Setting up of the Sensor[33]

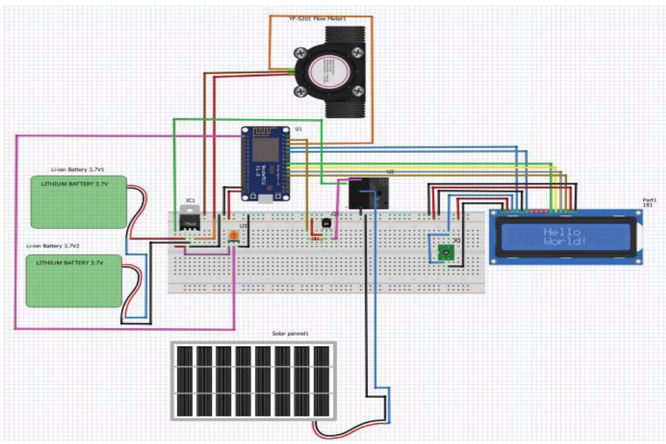

Figure 4. Complete circuit diagram

H. Display(LCD)

A 16 by 2 liquid crystal display is used as shown in Figure 4 to aid the display of total amount of water consumed so far.

I. Solar Charging Unit

This unit aids the green nature of the device. This ensures that the probability of outage is as low as possible. So as to ensure such achievement, the solar panel used must be able to charge the system effectively.

As specified earlier, to effectively power the system, 7.4V 6400mAh is needed. To charge the batteries and ensure that the life is not cut short, it is a common practice not to charge with more than one tenth of this current specification. Therefore, maximum of 640mA current is needed to charge the specified battery cell.

To achieve full charging within three hours, the following was considered

Total battery power $(P_{totalaB}) = V_{battery} \times I_{batterytotal}$

$$P_{totalB} = 7.4 \times 6400 mAh = 47.36 watth$$

Time it takes to charge the batter $(T_{charging}) = \frac{P_{totalB}}{P_{charging}}$

Let solar panel charge with 80% of the specified charging current.

$$I_{charging} = 0.8 \times 640 mA = 0.512 A$$

Charging with 8V solar panel

Charging power $(P_{charging}) = 0.512 \times 8 = 4.096W$

Charging time $(T_{charging}) = \frac{47.36}{4.096} = 11.6h$

This means it takes 11.6 hours to charge the battery when completely drained.

If it takes 11.6 hours to charge 7.4V battery, it will take:

$\frac{11.6 \times 5.5}{7.4} = 8.6h$ to charge it to 5.5V.

Therefore, it will take 3 hours to charge from 5.5V to full capacity.

J. Relay Unit

The relay used as shown in Figure 4 above is driven by a transistor A1015. To calculate the biasing resistor

$$V_{cc} = IR + V_{ce}$$

$$V_{cc} = V_{regulator} = 5V$$

$R = 100\,\Omega$ which is the resistance of relay coil.

$$I = I_{(collector)} < I_{\max(transistor)}$$

$V_{ce} = 0$ Since the transistor operates in two regions. This region includes saturation and cutoff.

$$V_{cc} = IR$$

$$I = \frac{V_{cc}}{R} = \frac{5}{100} = 0.05A$$

$$I_b = \frac{I_c}{hfe}$$

$hfe = 10$ is the current gain of the transistor.

$$I_b = \frac{0.05}{10} = 0.005(A)$$

$$V_b = I_b R_b$$

$V_b =$ base voltage which is approximately 5V

$R_b =$ biasing resistor at the base of the transistor

$$R_b = \frac{5}{0.005} = 1000$$

$$R_b = 1k\,\Omega$$

IV. EXPECTED RESULT

As stated earlier, our case study enjoys public power supply between the hours of 9am to 12 am. Also, at night they enjoy public power supply at 9pm to 12 pm. If the system is to run on public power supply,

$$T_{am} = T_{pm} = 3h$$

$$T_{p-avalable} = T_{am} + T_{pm} = 3 + 3 = 6h$$

Probability of outage $\Pr_{out}$ is given as

$$\Pr_{out} = 1 - \Pr_{avalable}$$

$$\Pr_{available} = \frac{T_{p-available}}{T_{day}} = \frac{6}{24} = 0.25$$

$$\Pr_{out} = 1 - 0.25 = 0.75$$

With the use of battery power which aids the system to be up by 16hrs before reaching the threshold

$$T_{blife} = 16h$$

$$T_{p-avalable} = T_{am} + T_{pm} + T_{blife} = 3 + 3 + 16 = 22hr$$

$$\Pr_{available} = \frac{T_{p-available}}{T_{day}} - \frac{22}{24} = 0.92$$

$$\Pr_{out} = 1 - 0.92 = 0.083$$

With the solar in place, charging the system in every 3hrs interval ensured the probability of outage will be near zero provided there are no down times in the network.

V. DISCUSSION OF RESULT

As observed, this study have proposed a design of green IoT based water monitoring system in Figure 4 that will monitor water consumption and drop this information on the cloud even in areas with poor or no power supplies.

Furthermore, it is anticipated from the results that via the use of green energy, the probability of outage is reduced by 67% . Hence power is compensated for.

VI. CONCLUSION

In conclusion, the system designed will be suitable for areas with no stable power like Tunga Minna Niger State Nigeria. Water could be monitored at all times of the day.

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