DEVELOPMENT OF AN AUTOMATED AQUAPONICS SYSTEM WITH HYBRID SMART SWITCHING POWER SUPPLY AND NET METERING

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CHAPTER 1

Introduction

The Philippines is an emerging economy and its economy has greatly shifted from agricultural then rapidly to industrial. The country in terms of agricultural damages has continued to rise due to unstoppable factors. The country is approximately 30 million hectares and 9.7 million of it is considered to be agricultural land. Coping up to the modern world, the country had gone Land Conversion to allow different infrastructures to be built. Rapid population growth increases the demand for more commercial land. Considering it's the most storm-exposed country on earth, these constraints contributed to agricultural damages [1]. Aquaponics is an obscure agricultural cultivation. It is the combination of aqua-culture system and hydroponics system. This agricultural cultivation is built indoor which provides the alternative solution for agricultural land unavailability and typhoon catastrophe [2]. The country is rich in renewable energy resources; hydropower, geothermal power, wind power, biomass power and the most abundant is solar power. Possessing a significant amount of sunlight, the country has the potential to produce 4.5 kWh to 5.5 kWh per square meter each day [3]. Aquaponics system is already practice in the Philippines. Taguig, Lucena, Cavite, Bulacan Alabang, Laguna, Bicol, Rizal and Cebu are one of the places who practices the system. There are only two commercial Aquaponics set up in the Philippines; Bay Aquaponics in Laguna and La Estrella Farms in Catagan. In which requires immense initial investment and high cost of energy consumption from running the system; which consists of pumps and aerators [4]. In the year 2017, the Philippines' Power consumption have reach 95 million gigawatt-hour, in which is a 4 percent increase from the year 2016. Power Industry

Executives expressed concern that the rapid increase in the demand will meet the energy used-produced boundaries. This power constraint up to present is still unsettled [5].

The country's state is facing agricultural constraints cause by commercialization, one example is decreasing agricultural land. There are numbers of option to counter this, one is building an aquaponics system. A recent study (Nagayo, Mendoza, Jamisola 2017) developed an Automated Solar-Powered Aquaponics System. This study was conducted and based in their nation, Oman. The study aimed to develop a sustainable low-cost automated control and monitoring system with minimal human intervention. The study focused on developing the system that is life sustaining for the plants and fishes passing the extreme season of cold winter and hot summer. The system mainly is composed of water pumps, microcontroller for the Aquaponics System and cooling-heating system inside a greenhouse. It is powered by a stand-alone solar panel system. The proponents concluded that the experimental results obtained during summer and winter season showed that the system is sustainable for the plants and fishes to be used in the country Oman. Urbanization is associated with increase of power demand [6]. A recent study (Neupane, Undeland, Rouniyar 2014) focused on designing a smart controller for Solar-Grid Hybrid System using microcontroller. The design uses digital signal processing for cost effective operation of solar-grid tied system. The purpose of the study is to give effective and efficient set-up of PV installation. Typically, Solar panel are used to collect energy from our sun and be stored in the battery backup for separate loads while the grid is the main source of the energy for the general loads of our homes; the problem encountered was the dumped energy. Dumped energy will occur when the PV system are still able to harvest energy while the battery backup is already fully charged. Effectively, the research provided the solution of using smart controller that were able to consequently helps both the load grid reduction as well as the energy metering in the household [7].

The study of Nagayo, Mendoza, Jamisola had focused on developing an automated aquaponics system in which composed of multiple sensors to obtain relative data and be transmitted through IOT in real time. While the study successfully developed the system powered in stand-alone PV system, the researcher have not taken consideration that weather is volatile. The researcher failed to consider to have back-up or other source of power in case there's deficiency in sunlight in times of changing weather and more so, changing season. The researcher have also failed to observe the efficiency of allocating the excess electricity collected for the PV system in case the battery is fully charged. The study of Neupane, Undeland, Rouniyar had focused of developing an a system that is able to make a new practice of installing solar panel with effective independency with the grid thus giving solution for the dumped energy from the solar system. As stated, grid is used as the main source of energy which feeds general loads at household including lightings, televisions, computers etc.; battery backup and solar energy is utilized with the separate circuit for separate critical loads that have to be utilized during the grid cut-off. While the study successfully developed the solution for allocating the dumped energy, the study have not considered to revert back the energy to the grid through the use of bidirectional meter, furthermore, the study have not use this practice in farming, particularly Aquaponics.

This research main objective is to develop an Automatic Aquaponics System with Hybrid Smart Switching Power Supply and Net Metering. The research specific objectives is first to design a small scale aquaponics system and integrated is with smart switching power supply system that is capable of powering the aquaponics system and revert energy. Second, the study objective is to compare the developed aquaponics system to the related research's power consumption. Third, the researcher aims to determine the total power that can be reverted to the utility. Forth, the researcher's objective is to determine the growth performance of the fish and plants by comparing it to the expected parameters.

The smart aquaponics system will play an important role in indoor farming system specially at urban areas where there is no enough land for agricultural cultivation. With the symbiotic relation of fishes to plant, this provides less allotted budget for water, irrigation s, as well as fertilizers in producing specific crops. By using solar power as renewable energy, we can also contribute on reducing the emissions of carbon dioxide. As a solution to the commercial aquaponic system constraint in the Philippines, it is beneficial by minimizing the dependability of the system to the utility. This study is relevant in maximizing the benefit of the collected energy from the photovoltaic installation by giving off the excess energy collected to the grid system, giving micro-change and contribute to the solution of power shortage in the country.

This study is limited in developing a Hybrid Smart Switching power supply for automated aquaponics system with net metering for advance farming. The study will only be monitoring the amount of power that the system consumed and the system's functionality to smart switch the system from using power from Solar or grid, it will also observe its functionality to revert energy into the utility. It will not be applied directly to the grid; therefore, a power inverter will be used rather than a grid-tied inverter. In terms of aquaponics, it will only be monitoring the total environmental condition of the system; water quality and environmental temperature per se. The research is concern with the life sustainability of the aquaponics, thus the research will be monitoring the quality, growth, survival rate of the plants and fishes. The plants to be observed is limited to Spinach or scientifically known as *Spinacia oleracea*, while the fish to be observed is

Oreochromis niloticus or commonly known as tilapia. This case is suited and adjusted to the Philippine climate set-up

CHAPTER 2

Review of Related Literature

2.1 Aquaponics System

Aquaponics is the combination of aquaculture and hydroponics that grows fish and plants at the same time in one integrated system. The aquaponics cycle starts from the fish that provides waste which serves as a fertilizer for the plants and the plants helps filtering the water for the fish. From the beneficial bacteria of the fish it is transformed to be the nutrients that a plant needs, by consuming these nutrients, it helps to purify the water. Harmful chemical and pesticides are not present in aquaponics because it's an eco-system. Aquaponics reduces the usage of fertilizers and pesticides (Engle 2015) [9]. This project aims to reduce the emissions of carbon dioxide using solar powered pumps and recycling of water from the drip irrigation method [10]. Aquaponics can be a good an essential part of "blue and green" infrastructure of urban areas and help urban areas food supply infrastructure [11]. In today's research from nutritional science, foods that are produced by aquaponics are the healthiest human nourishment.

2.1.1 Water Recirculation System

Water recirculation system operates the run of the water into an aquaculture tank for growing fishes and hydroponic beds which plants are placed where they grow. CHOP system is used in the aquaponics system. CHOP or "Constant Height One Pump" is one of the best systems that fits the health of the fish, which gives stability in both temperature and pH. Assuming the fish tank is full of water, the fish are safe whenever the pump goes wrong. Constant height is important to ensure that the fishes can't be pumped dry that comes from pump failure. One pump is used for economical purpose. This CHOP system is composed of a submersible pump that resides in the sump which serves as the central water flow in the system which delivers water to fish tank that has an overflow pipe connected to the hydroponic beds then drained back to the sump tank via bell siphon.

The system has a volume of 100 gallon which includes the water in the fish tank and in the grow beds. The flow rate of the system should have at least 200 gph. We set a 1:1 ratio of the fish tank volume to the grow bed volume. For a 75-gallon fish tank, having 3 half barrels of 55-gallon blue barrels were enough. The air flow requirement is 7.5 gph of air per gallon of tank water volume for the sufficiently supply of oxygen to the fish tank water [12]. Using the required air flow requirement for an 80-gallon fish tank is yielding 600 gph of air or about 40 lpm.

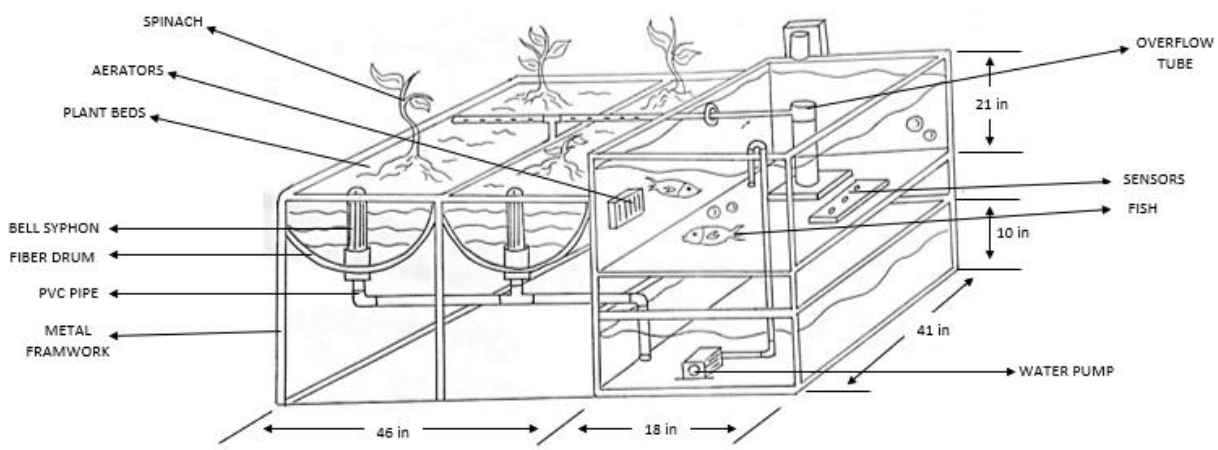


Figure 2.1.1 Water Recirculation System

2.1.2 An Automated Solar-Powered Aquaponics System towards Agricultural Sustainability in the Sultanate of Oman

The study had focused on developing an automated aquaponics system in which composed of multiple sensors to obtain relative data and be transmitted through IOT in real time. The researcher successfully developed the system powered in stand-alone PV system. They explained and presented the design, construction and implementation of water circulation system that circulates water to an aquaculture tank and hydroponic beds, they used Arduino microcontroller to control and monitor the system. They used actuators and different sensors as instrument to determine water parameters that will help to observe the habitable water condition [6].

2.1.3 Control and Monitoring of Water Quality Parameters

The water quality parameters of the aquaponics system such as water pH level, dissolved oxygen level, electrical conductivity, total dissolve solids and salinity, are controlled and monitored to maintain the best growth conditions of the fish in the aquaculture tank and the plants on the hydroponic beds.

Tilapia can survive a wide range of pH, from 5 to 10, but are said to grow best at pH 6 to 9. In tank systems, dissolved carbon dioxide causes pH to decline because of the formation of carbonic acid (H2CO3) in solution. Low pH is not as serious a problem in flow-through systems as in water reuse systems, in which a minimum pH of 6.8 is suggested as the lower limit of tolerance for the nitrifying bacteria of the biofilter. Due to the presence of dissolved carbon dioxide, high pH is generally not a problem in tank systems.

The dissolved oxygen (DO), Tilapia survive routine dawn dissolved oxygen (DO) concentrations of less than 0.3 mg/L, considerably below the tolerance limits for most other cultured fish. In research studies Nile tilapia grew better when aerators were used to prevent morning DO concentrations from falling below 0.7 to 0.8 mg/L (compared with unaerated control ponds). Growth was not further improved if additional aeration kept DO concentrations above 2.0 to 2.5 mg/L. Although tilapia can survive acute low DO concentrations for several hours, tilapia ponds should be managed to maintain DO concentrations above 1 mg/L. Metabolism, growth and, possibly, disease resistance are depressed when DO falls below this level for prolonged periods.

The electrical conductivity (EC) is a measure of how well the water in the aquaculture tank conducts electricity, and it is correlated to its salt content. Since EC specifies the total ionic content of water, this will indicate its freshness. In the aquaponics system, the set range of electrical conductivity is from EC >= 30 to EC <= 5,000 µS/cm based on the acceptable values specified by Stone and Thom Forde. If EC exceeds the predefined range, it indicates that the water is polluted and may cause death in fishes.

The total dissolved solids (TDS) indicates the amount of inorganic salt and dissolved organic matter in the aquaculture tank. Typically, the acceptable TDS value in mg/L is about half of EC in µS/cm. In the designed system, the normal value of TDS is set to TDS <= 2,500 mg/L. If TDS exceeds the pre-set range, it indicates that the water is polluted and may cause death in fishes.

The salinity (SL) indicates the salt concentration in water, in which fish are sensitive to. According to Grag and Bhatnagar [6], the desirable range of salinity level of water for aquaponics system is up to 2 ppt for common carp. In the aquaponic system, the set range of salinity is SL >= 0 to SL <= 2.0 ppt.

A Conductivity K 1.0 sensor is used to measure the EC, TDS and SL of the water in the aquaculture tank. If one of the parameters is not within the set range, the water pump (WP) is turned ON for 25% partial water replacement.

2.1.4 Plant *(Spinach)* Growth Parameters

The study focused on the plant growth conditions and the growth observation of the plant. Since cultivating or hand pulling weeds can harm spinach roots, it's best to spread a light mulch of hay, straw, or grass clippings along the rows to suppress weeds instead. Water stress will encourage plants to bolt, so provide enough water to keep the soil moist but not soggy. Cover the crop with shade cloth if the temperature goes above 80 degrees [15].

Spinach does best when growing in moist, nitrogen-rich soil. Spinach plants form a deep taproot; for best growth, loosen the soil at least 1 foot deep before planting. Since most spinach grows in very cool weather, pests are usually not a problem. Leafminer larvae can burrow inside leaves and produce tan patches. Prevent leafminer problems by keeping your crop covered with floating row cover. For unprotected plants, remove and destroy affected leaves to prevent adult flies from multiplying and further affecting the crop. Slugs also feed on spinach.

Spinach normally harvested during its 50^{th} day or six to eight weeks, you can start harvesting from any plant that has at least six three or four-inch-long leaves. Carefully cutting the outside leaves will extend the plants' productivity, particularly with fall crops. Harvest the entire crop at the first sign of bolting by using a sharp knife to cut through the main stem just below the soil surface. The agronomic efficiency of water use was calculated as the amount of water needed to produce one gram of dry matter [15].

Method in measuring Spinach Growth (Counting Leaves):

Frequency of Measurement (2-3 days)

- Count and record the number of leaves on each plant.
- Count every visible leaf on the plant, including the tips of new leaves just beginning to emerge.
- You may want to place the plant over some graph paper to avoid counting errors.

Method in measuring Spinach Growth (Surface Area of Leaves):

Frequency of Measurement (2-3 days)

- Trace the leaves on graph paper and count the squares covered to give you an estimate of the surface area for each leaf. Repeat this for each leaf on a plant and for each plant in your experiment.
- Trace out each leaf on paper. Make sure to use the same type of paper every time AND make sure that the paper is not wet. Cut out the leaf tracings and weigh them. Weigh the cutouts and divide the total weight by the number of leaves to give you the average leaf area for each plant. Repeat this for each of the plants in your experiment [16].

2.1.5 Fish *(Tilapia)* Growth Parameters

Measuring length and weight of live fingerling Tilapia. Measure the total weight of certain number of fishes, do it quickly with a clean water. In fishery there are different weight balance that is being used, A spring balance, a commercial weighing balance, and a roman-scale balance. From these three said weighing scales, it is better to use a spring balance. Hang the spring balance in a stable pole with a water bucket or a plastic bin. Fill the container as where the fish will be placed while weighing. The gross weight is equal to the weight of the fish plus the weight of the container with water inside. The individual whole fish was measured as body weight. The total length of fish was measured from the tip of the snout to the margin of the tail. The total length was taken to the nearest mm with a measuring scale and the body weight was taken to the nearest gram with an electronic digital balance [17]. To measure the fish length simply attached a flat measuring ruler graduated in millimeters and centimeters on the sides of the aquarium, this will be used to measure the fish length once they stay in the ruler. Use a camera to zoom-in and for data recording.

30 days		60 days		100 days	
Body weight (g)	AGR ($g \cdot d^{-1}$)	Body weight (g)	AGR ($g \cdot d^{-1}$)	Body weight (g)	AGR ($g \cdot d^{-1}$)
30.40±7.88	1.013	160.94±26.15	2.682	303.04±58.40	3.030

Figure 2.1.5: Growth Rate of Tilapia in three different months

2.1.6 Fish Population Based on Aquarium Volume

When determining the maximum number of tilapia fingerlings to put in an aquaponics system, only consider the gallons of water available to the fish for swimming. Do not count the water in the grow beds or other system components. The most widely known rule for stocking a tank is the one inch of fish per gallon of water rule. While this type of calculation works as a rough estimate, it leaves plenty of room for error. The larger the surface area of the water, the greater the oxygen exchange, which in turn supports a larger number of fishes. Therefore, the surface area of the water directly impacts how many fish can be kept in an aquarium. A tank that is tall and thin may hold the same number of gallons as a tank that is short and wide, yet they have vastly different surface areas [18].

The general consensus is that a pound of tilapia will need 3 gallons of water. A full-grown tilapia will weigh approximately 1 pound although they can grow larger. This may mean you only have 1 tilapia per 3 gallons or even per 6 gallons of water. You can increase the density of your fish by adding more grow beds; this will filter the water faster allowing more fish to be fed and stay healthy. [19].

2.1.7 Controlling and Monitoring of Environmental Parameters

The environment parameters include air temperature, relative humidity. These parameters are major limiting factors that affects the rate of photosynthesis in the environment. These parameters are controlled and monitored to have a good production of plants in the hydroponic beds.

DHT11 sensor is used to determine the temperature of air in $°C$ around the beds. The values accepted for air temperature are from $17°C\ to\ 30°C$ based. If $T_{air} < 10°C\ or\ T_{air} > 40°C$, a warning notification is sent to GUI on computer of the farm owner having an information on the condition of critical parameter of air temperature that can cause death in plants.

DHT11 sensor are also used for measuring the relative humidity (RH) of the growing plants. RH at 25% to 70% during daytime will not cause any problems according to a study “Managing the Greenhouse Environment to Control Plant Disease” (B. Eshenaur and R. Anderson, 2004). Growing plants at low RH leads to leaf dehydration and frequent watering, while growing plant at RH more than 85% causes mold and fungus growth. With these conditions, the normal values set for relative humidity in the designed greenhouse are from 40% to 70%. If RH > 70%, exhaust fan is turned on. If RH < 40 %, evaporative cooler is turned on. If RH < 25% or RH > 85%, a warning notification is sent to the farm owner for information of critical parameter.

Figure 2.1.7 75-gallon fish tank size (48’’ x 18’’ x 21’’)

Water Temperature, Optimum growth for tilapia is achieved at 81 to 84 °F (27 to 29 °C), but acceptable growth rates are reported at 77 to 90 °F (25 to 32 °C). Temperatures in the extreme upper range make it more difficult to maintain dissolved oxygen concentration.

2.1.8 Sensors

2.1.8.1 pH Sensor

pH meter is a scientific instrument that measures the hydrogen-ion activity in water-based solutions, indicating its acidity or alkalinity expressed as pH.

The pH level measures the acidity or alkalinity of the water in the aquaculture tank and hydroponic beds. The tolerance range of pH level for most plants is 5.5 to 7.5. If the pH goes beyond the acceptable range, plants experience nutrient deficiencies (C. Sommerville et al). On the other hand, fish in fresh water aquaculture tank can tolerate a wide range of pH from 5.5 to 10 [13], but they grow best in waters with a pH ranging from 6.0 to 9.0 [14]. With these conditions, the set normal range of pH level sensor in the designed aquaponics system is from 5.5 to 8.0 ppm. If the pH sensor circuit reads a value of pH < 5.5 or pH > 8.0, the water pump (WP) is turned on for 25% partial water replacement.

2.1.8.2 Water Temperature Sensor

A D18B20 temperature sensor is used to determine the hotness or coldness of water in oC inside the aquaculture tank. The set normal range for the water temperature (Twater) is 16 to 33 oC. If Twater > 33 oC, water pump (WP) is turned on for 25% partial water replacement. If water temperature is too high, the fish will stop feeding and the plants will start to wilt [11]. An ultrasonic sensor was used to measure the water level from the top of the clean water supply tank in centimeters. If Twater < 16 oC, warmer lamps (W) are turned ON. If the water is too cold, nitrifying bacteria will stop working and some fish may not eat properly then they become vulnerable to diseases [20].

2.1.8.3 Dissolved Oxygen Sensor

It is used to perform a wide variety of experiments to determine changes in dissolved oxygen levels, one of the primary indicators of the quality of an aquatic environment. The dissolved oxygen (DO), Tilapia survive routine dawn dissolved oxygen (DO) concentrations of less than 0.3 mg/L, considerably below the tolerance limits for most other cultured fish. In research studies Nile tilapia grew better when aerators were used to prevent morning DO concentrations from falling below 0.7 to 0.8 mg/L (compared with unaerated control ponds).

2.1.8.4 Electrical Conductivity Sensor

It is used to conduct an electric current. Salts or other chemicals that dissolve in water can break down into positively and negatively charged ions.

2.1.8.5 Total Dissolved Solid Sensor

It is a small hand-held device used to indicate the Total Dissolved Solids in a solution, usually water. Since dissolved ionized solids, such as salts and minerals, increase the conductivity of a solution, a TDS meter measures the conductivity of the solution and estimates the TDS from that reading [21].

The total dissolved solids (TDS) indicates the amount of inorganic salt and dissolved organic matter in the aquaculture tank. Typically, the acceptable TDS value in mg/L is about half of EC in µS/cm. In the designed system, the normal value of TDS is set to TDS <= 2,500 mg/L. If TDS exceeds the pre-set range, it indicates that the water is polluted and may cause death in fishes.

2.1.8.6 SL Sensor

It is used a high frequency procedure to measure the concentration, and changes in concentration in chemicals.

2.1.9 Actuators

2.1.9.1 Aerators

It is used to provide a pond with oxygen. Oxygen is of vital importance for a water tank equipped with fish and plants. Throughout the year, in summer fish are often suffering from lack of oxygen owing to hot weather. An oxygen pump will supply oxygen to the water whereas it will discharge harmful gases. This should be installed beside a water tank. Through a hose the pump will pump air into your water tank and it provides additional oxygen. An air pump also makes use of aeration stones.

2.1.9.2 Water Pump

Diesel pumps are fuel dependent and cheaper than solar-powered pumps, but the maintenance and operational cost are higher because they depend on the diesel price which varies nowadays. In solar-powered system, there is no operational cost since renewable energy is free.

Pumps are usually powered by DC motors directly from the output of the solar panels. AC motors can be use also but you need an inverter to convert the DC electricity generated by solar panels to AC electricity. According to NRCS (2010), The objective of the pumps is by using the solar energy wisely on the system by having a storage tank of water into the system [18].

A pump controller is part of solar-powered pump which controls the output power that pump receives from the input power available in solar panels. Pump controller has a feature of where the systems automatically off when the voltage is too low or too high for the operating range of the pump which can help reduce maintenance of the pump. The good thing about pump controller is it can have inputs from the grid and solar panel at the same time which will give importance in this study [19].

2.2 Photovoltaic System

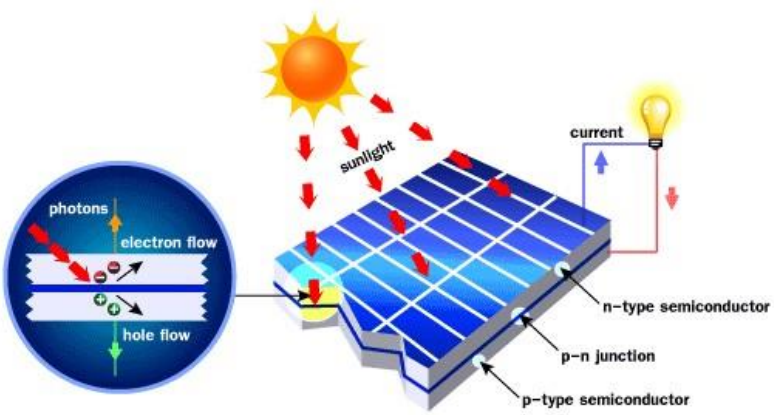


Figure 2.2 *How Solar Panel works*

Photovoltaic panels capture the sun’s energy as a source of renewable energy which generates electricity. Generation of electricity comes from photons that hits solar cells by the means of knocking of electrons loose from their atoms that flows into semiconductors attached to positive and negative side of a cell. PV solar panels generates DC electricity as electrons flow in one direction. Single junction panels are used most of the time but nowadays, multijunction panels are used to generate voltage by the means of two or more different cells to sum up a higher energy efficiency [22]. To change DC to AC electricity we use an inverter. Solar panels are well-known in generating clean, emission free electricity [23].

Given: Per day = 4758 watt-hour
Ave. sunlight per day = 5.75

Per month = 4758 watt-hours x 30days= 142740 watt-hours

$$\frac{4758\ watt-hours}{5.75\ avg.sunlight\ perday} = 827.4783 \text{ Watts}$$

Therefore, use three 300 watts solar panel 28V PV

2.2.1 Battery Life Prolonging 50%

2.2.2 Computation of Size of Photovoltaic System (ANGLE)

For us to design the best Photovoltaic system, first is we have to compute for the battery capacity. The battery capacity is measured in Ampere hours. Convert this to Watt hours by multiplying the Ampere hour by the battery voltage [24].

- X (Battery size in AH) x Y (Battery Voltage) = Z (Power available in watt hours
- For a 20AH, 12V battery the Watt Hours figure is 20(X) x 12(Y) = 240 WH (Z)

Second, know how much energy will the Aquaponic system will use over a period of time.

- The 20W Load, on for 2 hours, will take 20 x 2 = 40WH from the battery.

Third, is how determining how much your solar panel generate over a period of time. In a tropical area like the Philippines. Mostly Day will generate more power than night since sun is present in day.

- On 10:30am regular day, a 10W panel can provide a 60W worth of energy to be stored in battery (10w x 6 = 60w).

Finally, the computation of the total Area of your Solar panel that would be needed to run a system is given below.

- Watts required / time of year sunshine hours = panel size → 196 / 6 = 32.6W panel, a 32.6W panel is not available in the market so 30W or 40W is recommended for this type of application.

2.3 Net Metering

Net metering is an eco-friendly method that generate the gathered electricity from the solar panel to feed the excess electricity back into the grid. It measures the amount of energy gathered by the solar panel and measures the amount of energy consumed by the system. A utility system that involves two-way flow of electricity. All excess electricity from the system will be sent back to the grid. When the system is working on day, it can generate more electricity than the system consumes during daylight hours [25].

2.3.1 Bidirectional Net-Meter

Bi-directional metering is a process that measures the flow of electricity into two direction, first supplying the grid and second is by absorbing electricity to the grid in the absence of main source. It measures how much energy comes from your electric company. It also measures the difference between the generators production and the customers load demand.

This method is only available to a customer who installed renewable fuel generators such as solar, wind, hydro or biomass sources and operate the generator in parallel with their electric company's electrical system.

2.3.2 Grid-Tied Inverter

A grid-tie inverter (GTI) is also known as "synchronous inverter" or its technical name "grid-interactive inverter". It cannot be used in standalone applications where utility power is not available.

This is a special type of power inverter that converts direct current (DC) electricity from the solar panels into alternating current (AC) and feeds it into an existing electrical grid.

It works by regulating the amount of voltage and current that is received from the direct current solar panels (or other renewable energy/DC sources) [26].

- During a period of overproduction from the solar generating system, power is routed into the power grid, thereby being sold to the local utility provider.
- During insufficient power production from the solar generating system, it allows for power to be purchased from the local utility provider

Paper of Robertson and Du proposes a novel, cost-effective grid-connected inverter for a domestic micro combined heat and power system. A high-frequency (~12 000 r/min), high-voltage (~425 Vdc) brushless dc machine is used as the generator. The output of the generator is injected into the grid through a novel grid-connected inverter, utilizing a digital algorithm for the implementation of a constant frequency hysteresis current control. This allows a simplified output filter with smaller components to be employed. A grid synchronization method has also been designed, based on a low-pass filter and a microcontroller to optimize/tune the output power factor. The proposed method is successfully applied to a 500-W, 230-V, 50-Hz grid-connected voltage-source inverter (VSI) prototype, where the output of the VSI has been demonstrated to comply with the operating regulations for domestic distributed power generation systems [27].

2.3.3 Net Metering Standard (ERC)

According to Energy Regulatory Commission there are rules enabling the Net-Metering program for renewable energy. Any RE system causing interference, problems, or any unacceptable parameters to the DU's Distribution System shall be disconnected by the DU from the Distribution System and shall remain disconnected until the condition has been corrected, provided that reasonable notice is given on the intent to disconnect, and the QE is given at least three (3) days within which to remedy the hazardous condition. If the cause of the problem is the RE system, all costs associated with determining and correcting the problem shall be at the QE's expense.

2.3.3.1 Voltage Level

The QE shall operate its facility maintaining the same voltage level as the DU's Distribution System at the Connection Point. The QE must provide an automatic method of disconnecting its facility from the Distribution System within DU's limits.

RE System	
Voltage Range (% of Base Voltage)	Time (s)
V<50	0.16
50≤V<90	2.00
90<V ≤110	Normal Operating Range
110<V<120	1.00
V≥120	0.16

Table 2.3.3.1 – Minimum Time Requirements for RE to Remain Connected at Different Voltage Ranges

2.3.3.2 Frequency

All RE systems shall operate at a frequency of 60 Hz. The QE shall provide automatic disconnection means from the DU's Distribution System within the time prescribed in Table 2.3.3.2.

RE System	
Frequency Range (Hz)	Time
F > 62.4	Automatic disconnection
61.8 < F ≤ 62.4	5 minutes
58.2 ≤ F ≤ 61.8	Continuous Operation
57.6 ≤ F < 58.2	5 minutes
F < 57.6	5 seconds

Table 2.3.3.2 - Minimum Time Requirements for RE to Remain Connected at Different Frequency Ranges

2.3.3.3 Limitation of Direct Current (DC) Injection

The RE system and its interconnecting system shall not inject DC greater than 0.5% of the full load rated output current at the Connection Point.

2.3.3.4 Flicker Severity

The flicker severity at the Connection Point shall not exceed 1.0 unit for short term and 0.8 units for long term as specified in Section 3.2.6 of the PDC, or any subsequent amendments thereto.

2.3.3.5 Harmonics

The harmonic content of the voltage and current waveforms in the DU's Distribution System shall be restricted to levels that will not cause interference or equipment-operating problems. The harmonics shall be within the limits defined in Section 3.2.4 of the PDC or any subsequent amendments thereto.

2.3.3.6 Power Factor

The QE shall maintain a power factor of not less than 85% lagging, measured at the Connection Point. Failure to maintain the power factor within this range may result in rate penalties and/or discontinuation of interconnection with the DU's Distribution System.

2.4 Smart Switching

Smart Grid Switching system is a process that develop a device that can switch sources connected to a load to sort difference sources. Smart Device switches between sources according to the priority given to various incoming sources taking into consideration that which source among the present source is the most economical at the same time the best source for the load in that time. The purpose of using this device is to provide uninterrupted power supply to a load, by selecting the supply from any source that is available to run the system.

2.4.1 Relay

Relays are switches that open and close circuits electromechanically or electronically. Relays control one electrical circuit by opening and closing contacts in another circuit**.** The Aquaponic System can be fully automated, with relay-controlled pumps, and sensors to detect humidity, temperature, soil moisture, and water level in the fish tank. It’s got a backup air pump to save your fish if the power goes out, and a master system kill relay in case anything goes wrong. You can manually turn something on or off using your computer, tablet or phone, from anywhere. Some automation examples include toggling the relay based on environmental conditions, sensor reports, time, or some combination of these.

2.4.2 Microcontroller operation

The microcontroller is programmed to function as automated switch and distinguish the battery’s percentage level of charge. It identifies the condition of the batteries whether its low or fully charged. The logic of the microcontroller is to automatically switch the system’s power source from the utility to PV installations, vice versa. The dependency of the system relies on the status of the battery. If the battery status has reach below 50%, the microcontroller function to switch the systems source to grid and at the same the PV installation will change its battery till ready. If the current battery status is above 50%, the systems will be dependent on the stored energy and at the same time the collected energy from the photovoltaic installation will be reverted to the utility. According to the study, deep cycle batteries should not discharge more than 50 percent depth of discharge to have a longer life of the battery.

2.5 LabView

LabVIEW offers a graphical programming approach that helps you visualize every aspect of your application, including hardware configuration, measurement data, and debugging. This visualization makes it simple to integrate measurement hardware from any vendor, represent complex logic on the diagram, develop data analysis algorithms, and design custom engineering user interfaces.

LabVIEW is essentially an environment that enables programming in G – this is a graphical programming language created by National Instruments that was initially developed to communicate via GPIB, but since then it has been considerably updated. Nowadays, G can be used for automated test applications, general data acquisition, programming FPGAs, etc . . . .

This is used for monitoring purposes, the real-time data gathered by the Arduino microcontroller are displayed in LCDs and in graphical user interfaces (GUIs). LabView also control the necessary water quality parameters for healthy fish. In Aquaponics, LabVIEW program can be a useful tool in reading and logging values for all the parameters used in the system

Chapter 3

DEVELOPMENT OF AN AUTOMATED AQUAPONICS SYSTEM WITH HYBRID SMART SWITCHING POWER SUPPLY AND NET METERING

Methodology

Introduction

The Philippines is an emerging economy and its economy has greatly shifted from agricultural then rapidly to industrial. The country in terms of agricultural damages has continued to rise due to unstoppable factors. The country is approximately 30 million hectares and 9.7 million of it is considered to be agricultural land. Coping up to the modern world, the country had gone Land Conversion to allow different infrastructures to be built. Rapid population growth increases the demand for more commercial land. Considering it's the most storm-exposed country on earth, these constraints contributed to agricultural damages [1]. Aquaponics is an obscure agricultural cultivation. It is the combination of aqua-culture system and hydroponics system. This agricultural cultivation is built indoor which provides the alternative solution for agricultural land unavailability and typhoon catastrophe [2]. The country is rich in renewable energy resources; hydropower, geothermal power, wind power, biomass power and the most abundant is solar power. Possessing a significant amount of sunlight, the country has the potential to produce 4.5 kWh to 5.5 kWh per square meter each day [3]. Aquaponics system is already practice in the Philippines. Taguig, Lucena, Cavite, Bulacan Alabang, Laguna, Bicol, Rizal and Cebu are one of the places who practices the system. There are only two commercial Aquaponics set up in the Philippines;

Bay Aquaponics in Laguna and La Estrella Farms in Catagan. In which requires immense initial investment and high cost of energy consumption from running the system; which consists of pumps and aerators [4]. In the year 2017, the Philippines' Power consumption have reach 95 million gigawatt-hour, in which is a 4 percent increase from the year 2016. Power Industry Executives expressed concern that the rapid increase in the demand will meet the energy used-produced boundaries. This power constraint up to present is still unsettled [5].

The country's state is facing agricultural constraints cause by commercialization, one example is decreasing agricultural land. There are numbers of option to counter this, one is building an aquaponics system. A recent study (Nagayo, Mendoza, Jamisola 2017) developed an Automated Solar-Powered Aquaponics System. This study was conducted and based in their nation, Oman. The study aimed to develop a sustainable low-cost automated control and monitoring system with minimal human intervention. The study focused on developing the system that is life sustaining for the plants and fishes passing the extreme season of cold winter and hot summer. The system mainly is composed of water pumps, microcontroller for the Aquaponics System and cooling-heating system inside a greenhouse. It is powered by a stand-alone solar panel system. The proponents concluded that the experimental results obtained during summer and winter season showed that the system is sustainable for the plants and fishes to be used in the country Oman. Urbanization is associated with increase of power demand [6]. A recent study (Neupane, Undeland, Rouniyar 2014) focused on designing a smart controller for Solar-Grid Hybrid System using microcontroller. The design uses digital signal processing for cost effective operation of solar-grid tied system. The purpose of the study is to give effective and efficient set-up of PV installation. Typically, Solar panel are used to collect energy from our sun and be stored in the battery backup for separate loads while the grid is the main source of the energy for the general loads of our homes; the problem encountered was the dumped energy. Dumped energy will occur when the PV system are still able to harvest energy while the battery backup is already fully charged. Effectively, the research provided the solution of using smart controller that were able to consequently helps both the load grid reduction as well as the energy metering in the household [7].

The study of Nagayo, Mendoza, Jamisola had focused on developing an automated aquaponics system in which composed of multiple sensors to obtain relative data and be transmitted through IOT in real time. While the study successfully developed the system powered in stand-alone PV system, the researcher have not taken consideration that weather is volatile. The researcher failed to consider to have back-up or other source of power in case there's deficiency in sunlight in times of changing weather and more so, changing season. The researcher have also failed to observe the efficiency of allocating the excess electricity collected for the PV system in case the battery is fully charged. The study of Neupane, Undeland, Rouniyar had focused of developing an a system that is able to make a new practice of installing solar panel with effective independency with the grid thus giving solution for the dumped energy from the solar system. As stated, grid is used as the main source of energy which feeds general loads at household including lightings, televisions, computers etc.; battery backup and solar energy is utilized with the separate circuit for separate critical loads that have to be utilized during the grid cut-off. While the study successfully developed the solution for allocating the dumped energy, the study have not considered to revert back the energy to the grid through the use of bidirectional meter, furthermore, the study have not use this practice in farming, particularly Aquaponics.

This research main objective is to develop an Automatic Aquaponics System with Hybrid Smart Switching Power Supply and Net Metering. The research specific objectives is first to design a small scale aquaponics system and integrated is with smart switching power supply system that is capable of powering the aquaponics system and revert energy. Second, the study objective is to compare the developed aquaponics system to the related research's power consumption. Third, the researcher aims to determine the total power that can be reverted to the utility. Forth, the researcher's objective is to determine the growth performance of the fish and plants by comparing it to the expected parameters.

The smart aquaponics system will play an important role in indoor farming system specially at urban areas where there is no enough land for agricultural cultivation. With the symbiotic relation of fishes to plant, this provides less allotted budget for water, irrigation s, as well as fertilizers in producing specific crops. By using solar power as renewable energy, we can also contribute on reducing the emissions of carbon dioxide. As a solution to the commercial aquaponic system constraint in the Philippines, it is beneficial by minimizing the dependability of the system to the utility. This study is relevant in maximizing the benefit of the collected energy from the photovoltaic installation by giving off the excess energy collected to the grid system, giving micro-change and contribute to the solution of power shortage in the country.

This study is limited in developing a Hybrid Smart Switching power supply for automated aquaponics system with net metering for advance farming. The study will only be monitoring the amount of power that the system consumed and the system's functionality to smart switch the system from using power from Solar or grid, it will also observe its functionality to revert energy into the utility. It will not be applied directly to the grid; therefore, a power inverter will be used rather than a grid-tied inverter. In terms of aquaponics, it will only be monitoring the total environmental condition of the system; water quality and environmental temperature per se. The research is concern with the life sustainability of the aquaponics, thus the research will be monitoring the quality, growth, survival rate of the plants and fishes. The plants to be observed is limited to Spinach or scientifically known as *Spinacia oleracea*, while the fish to be observed is *Oreochromis niloticus* or commonly known as tilapia. This case is suited and adjusted to the Philippine climate set-up

Conceptual Framework

The figure 3.1 shows the conceptual framework study of Automated Aquaponics System with Hybrid Smart Switching Power supply with net metering. Plants (spinach) are placed in the hydroponic bed and fishes (tilapia) are placed into the aquarium. The energy collected from the photovoltaic system, and Tilapia and Spinach are the inputs of the system . There are three major process of the system; Water recirculation, Microcontroller Sensor and Processing, Power Smart Switching. Outputs would be GUI NI LABVIEW, Kilowatt-hour Consumption , Excess Energy, and Growth of Tilapia and Spinach.

INPUT

- Spinach and Tilapia
- Solar energy that supply power to the system.

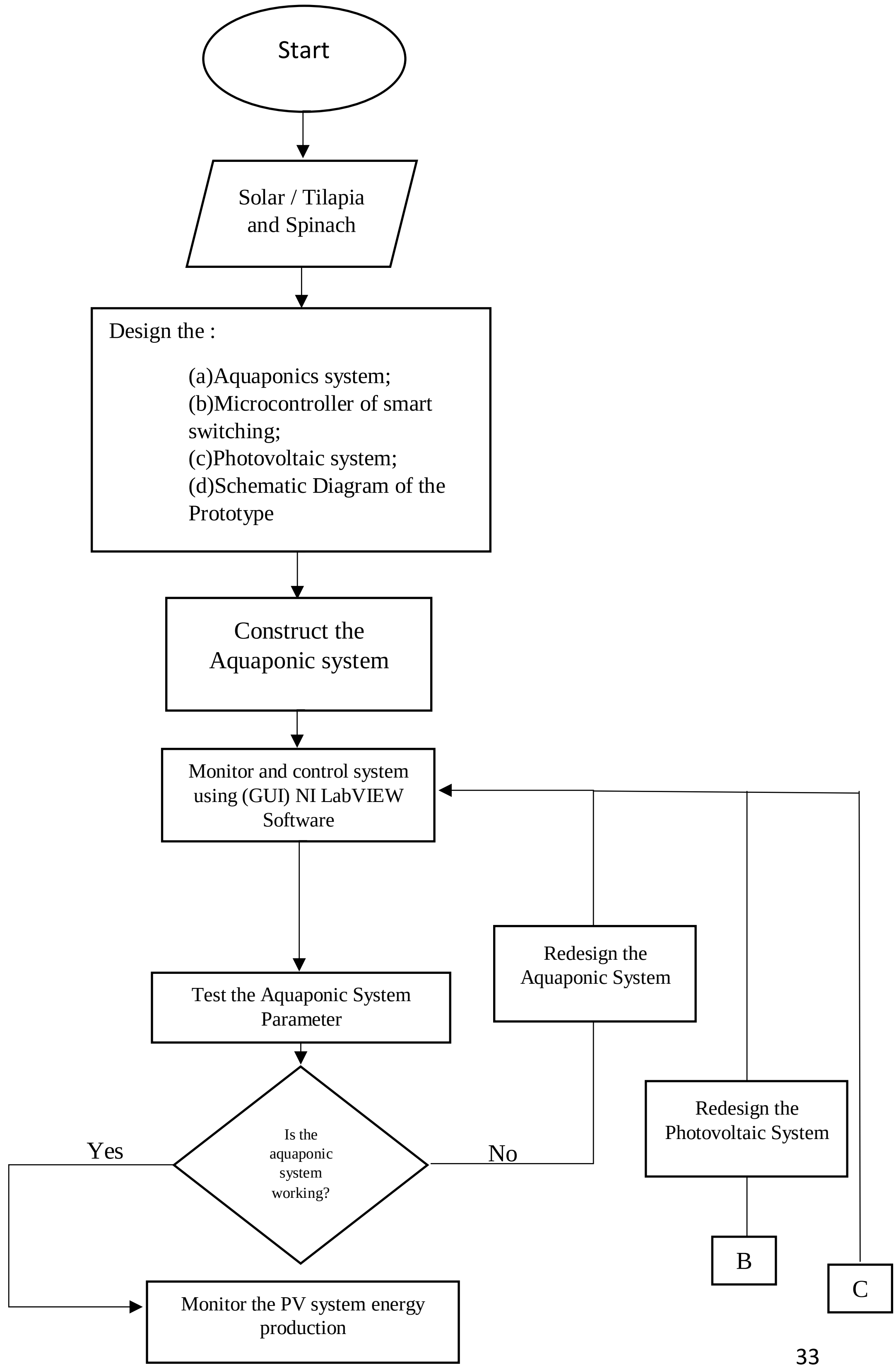
Process

- Water recirculation system
- Arduino microcontroller reads and processes data of water quality parameters and environmental parameters.
- Monitor of Energy and Smart Switching system

Output

- Actuators conduct a controlled operation from the condition of sensors.
- Data displayed in (GUIs) NI LABVIEW software of aquaponic control and monitoring.
- Kilowatt-hour Consumption
- Excess power from solar PV system will be delivered to the grid.
- Growth of Tilapia and Spinach

Figure 3.1 Conceptual Framework of Automated Aquaponics System with Hybrid Smart Switching Power supply and net metering



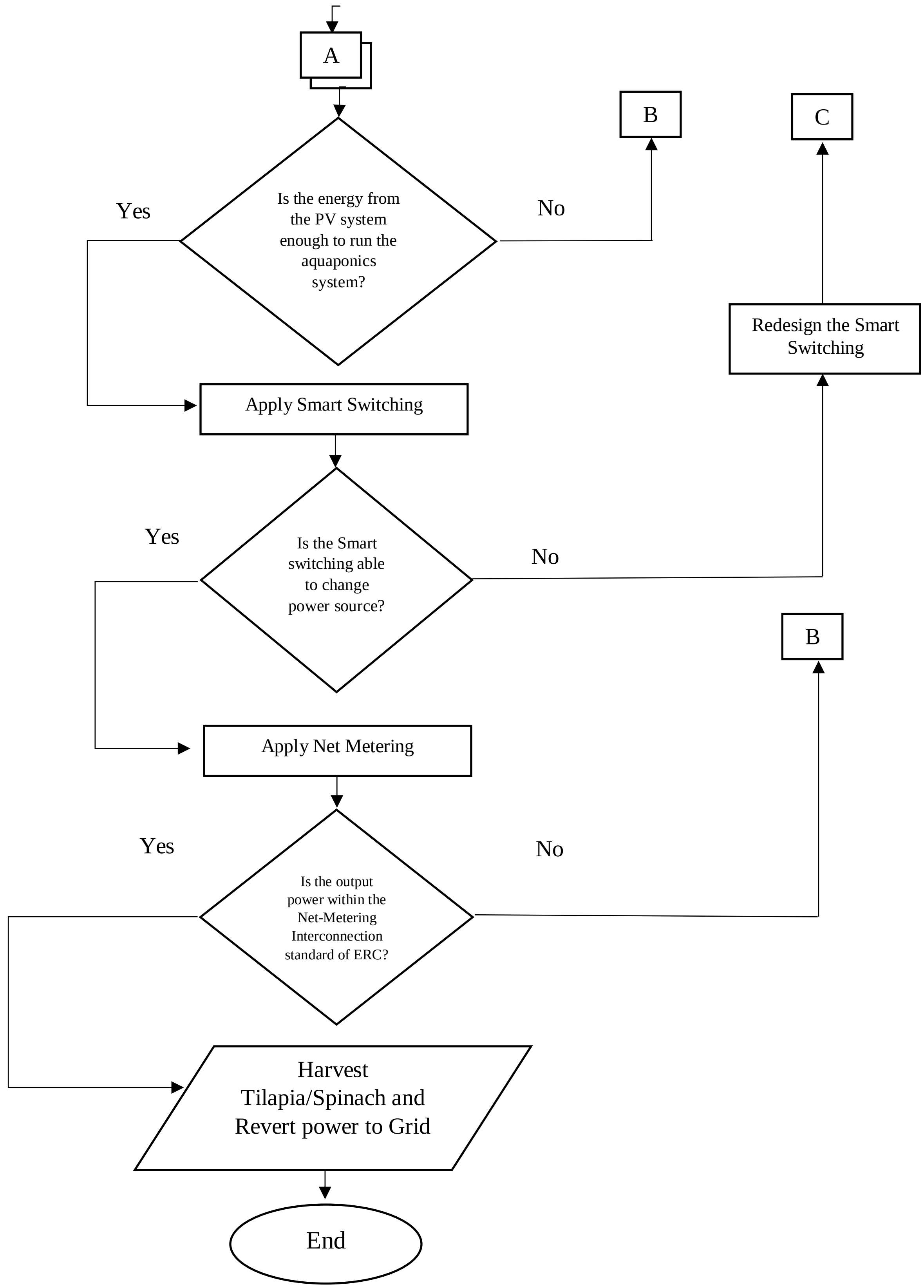
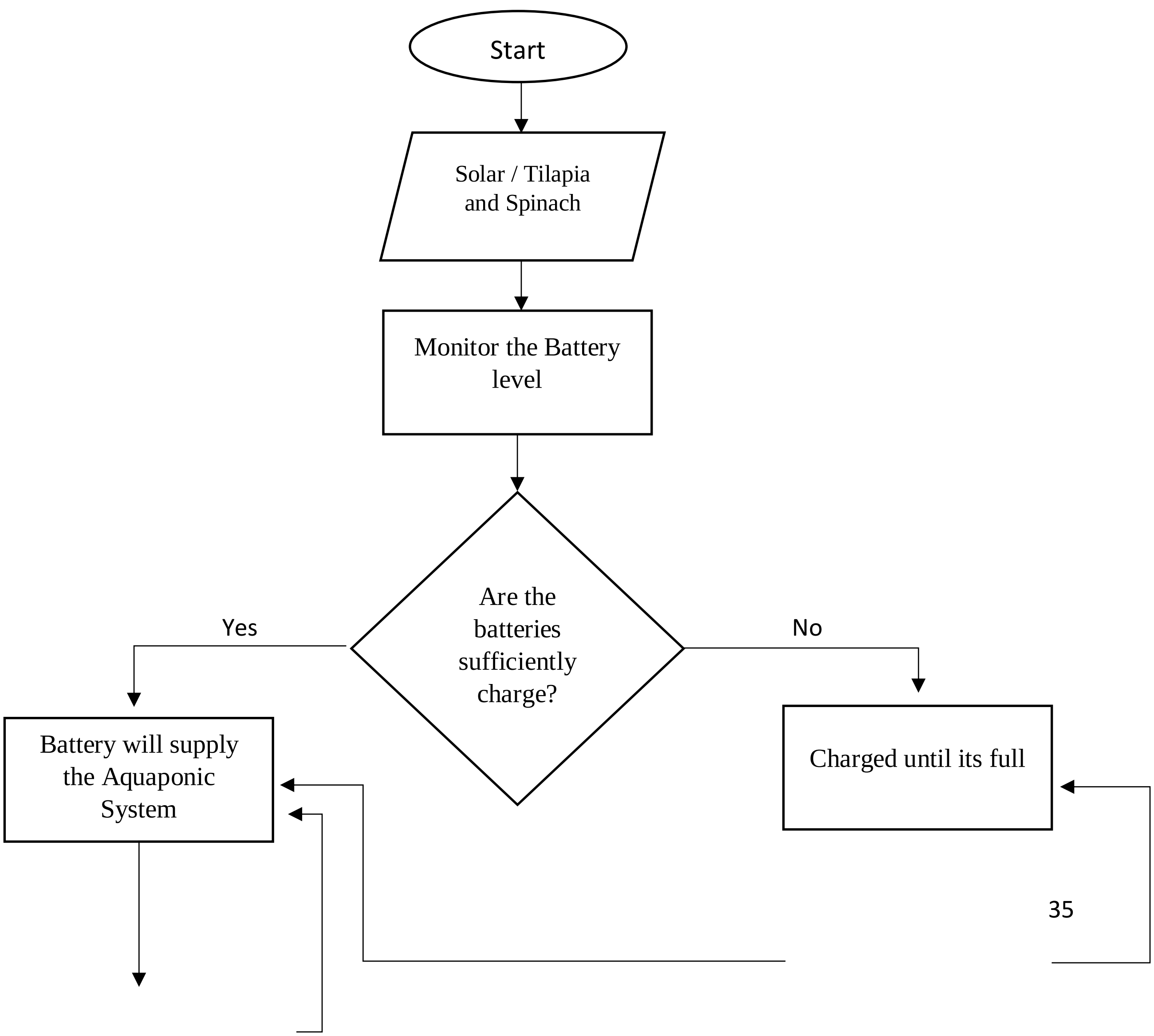

A
B
C
Yes
Is the energy from the PV system enough to run the aquaponics system?
No
Redesign the Smart Switching
Apply Smart Switching
Yes
Is the Smart switching able to change power source?
No
B
Apply Net Metering
Yes
Is the output power within the Net-Metering Interconnection standard of ERC?
No
Harvest Tilapia/Spinach and Revert power to Grid
End

Figure3.2 Design procedure of Automated Aquaponics System with Hybrid Smart Switching Power supply and net metering

The design procedure of the Automatic Aquaponics System with Hybrid Smart Switching Power Supply and Net Metering have Solar Energy, and Tilapia and Spinach as its input. In order to gain the study output, for a start, the Aquaponics system, Microcontroller of smart switching, Photovoltaic system, schematic diagram of the prototype must be designed and then be constructed. Each sector's functionality is to be tested. If the sector didn't meet the expected functionality, it should be redesigned and reconstructed in order to meet the needed output, in which is the Harvest Tilapia and Spinach, and Reverted Energy.



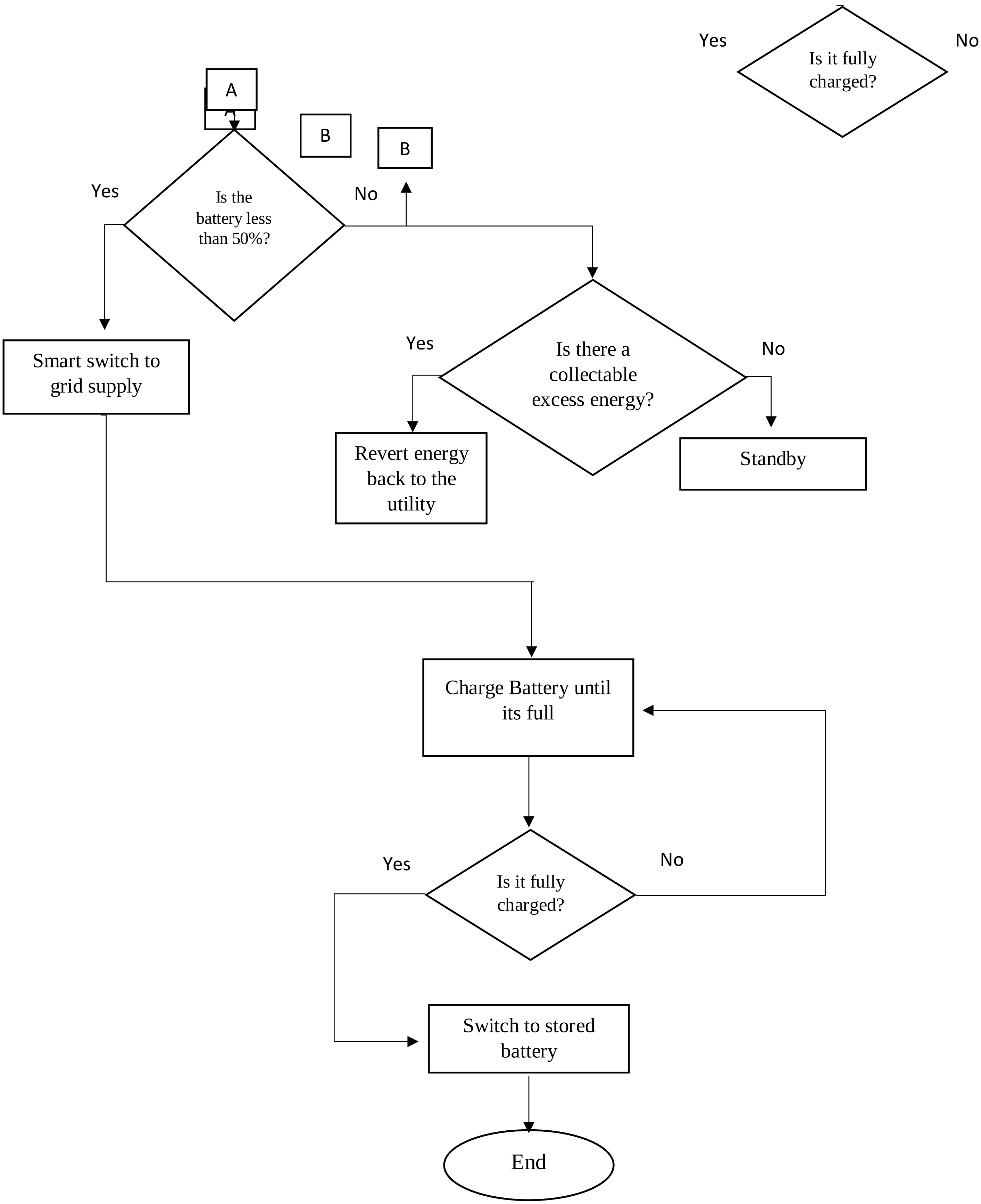
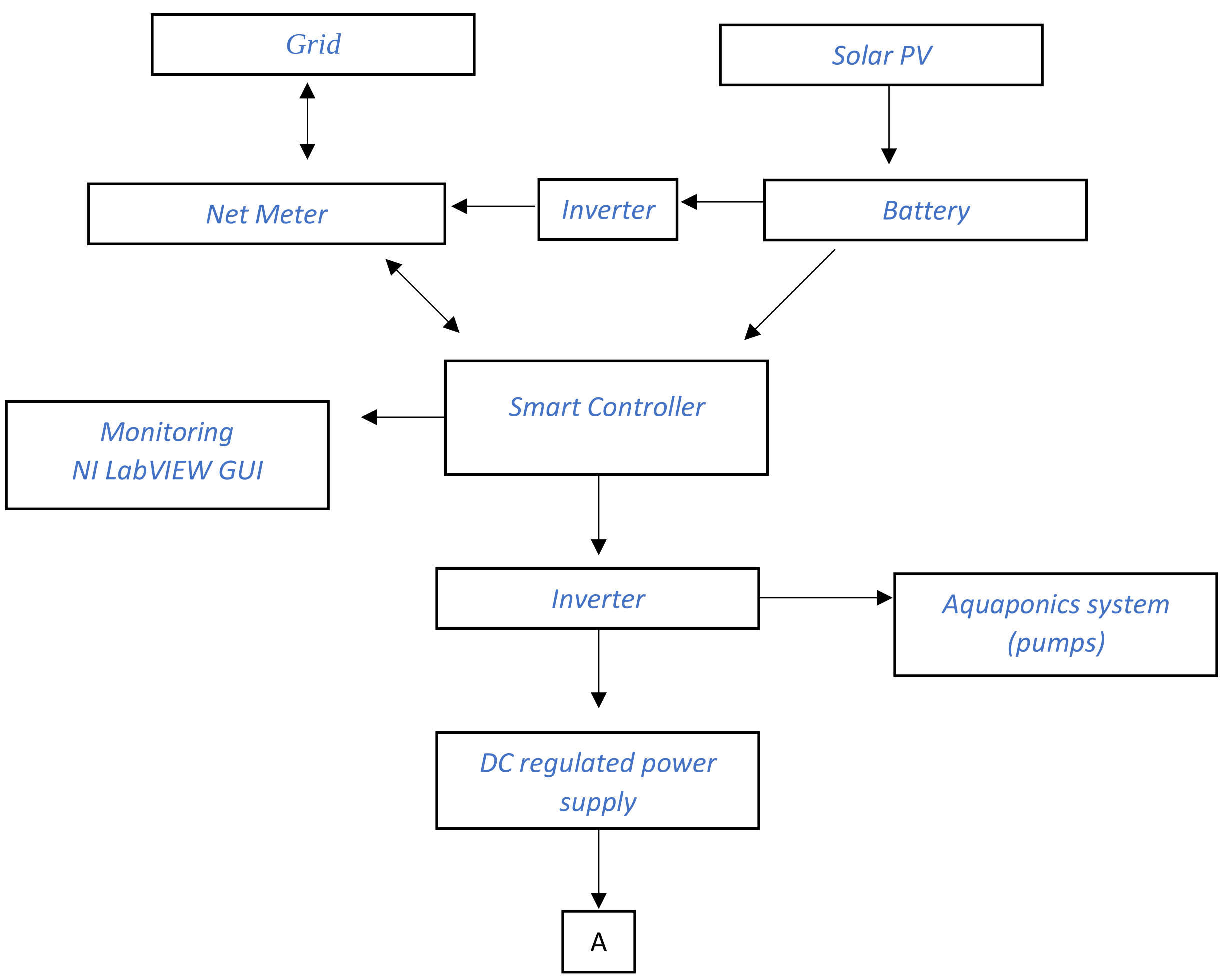

Yes
Is it fully charged?
No
A
A
B
B
Yes
Is the battery less than 50%?
No
Smart switch to grid supply
Yes
Is there a collectable excess energy?
No
Revert energy back to the utility
Standby
Charge Battery until its full
Yes
Is it fully charged?
No
Switch to stored battery
End

Figure 3.3 Process Flowchart of Automated Aquaponics System with Hybrid Smart Switching Power supply and net metering

The Process Flowchart of Automated Aquaponics System with Hybrid Smart Switching Power supply and net metering has Solar Energy, Tilapia and Spinach as inputs. The flow of the system is mainly dependent on the status of the system's battery. Through the Labview, the battery level is constantly monitored. If the battery is considered to be sufficiently charged, it will supply the system, otherwise it will be charged till full and the aquaponics system is power dependent to the utility. In an instance that the battery is sufficiently charged and there is a collectable solar power it will be smart-switch.



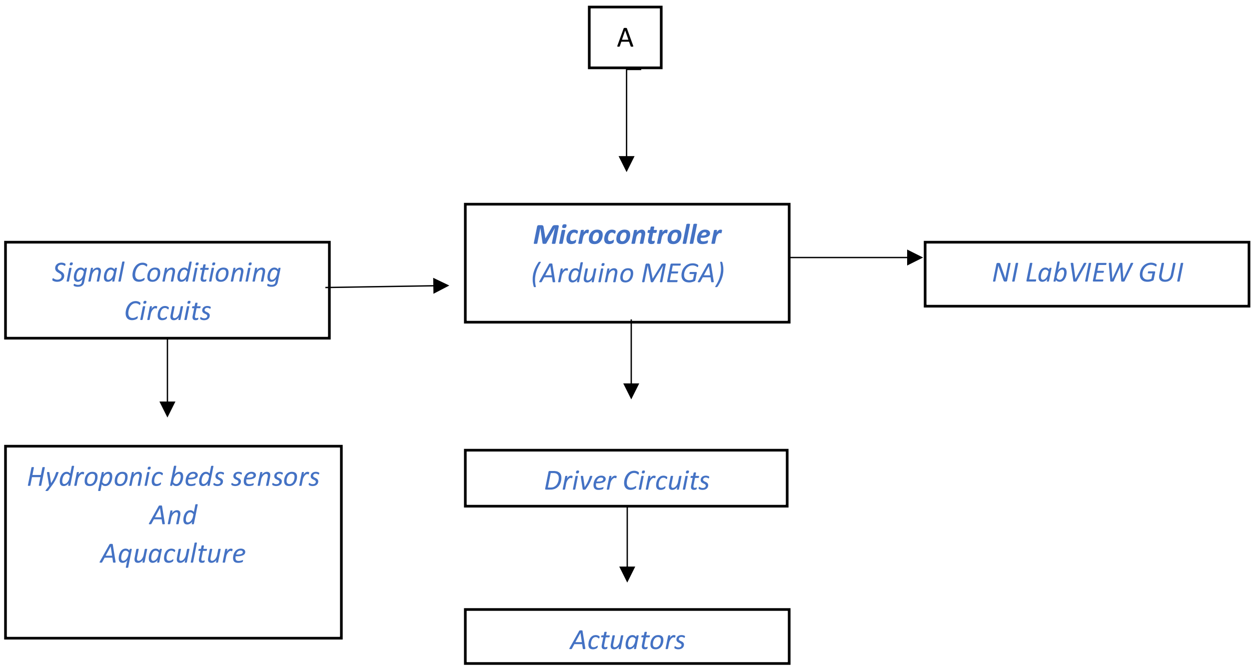


Figure 3.4 Block Diagram of Automated Aquaponics System with Hybrid Smart Switching Power supply and net metering

The block diagram of the Process Flowchart of Automated Aquaponics System with Hybrid Smart Switching Power supply and net metering begins at the two available power sources. Starting from the Solar PV, energy can be either be stored or be proceeded to the inverter. All are shown unidirectional except for the Net Metering; this show the application of reverting excess collected energy. All aquaponics parameters to be sense are delivered to the LabView GUI. Parameter are set for the better habitat of the organisms and be automatically adjusted by the microcontroller.

3.1 Design of Small-Scale Aquaponics with Hybrid Smart Switching

3.1.1 Aquaponics System

The designed system consists of two tanks and a plant bed. One of the tanks is used on aquarium and other is for sump tank. The 75-gallon Aquarium's dimensions is 41 x 18 x 21 inches and is made from glass, while the 40-gallon sump tank's dimension is 41 x 18 x 10 inches also made out of glass. Water recirculation system operates the run of the water into an aquaculture tank for growing fishes and hydroponic beds which plants are placed where they grow. CHOP system is used in the aquaponics system. CHOP or "Constant Height One Pump" is one of the best systems that fits the health of the fish, which gives stability for the water level.

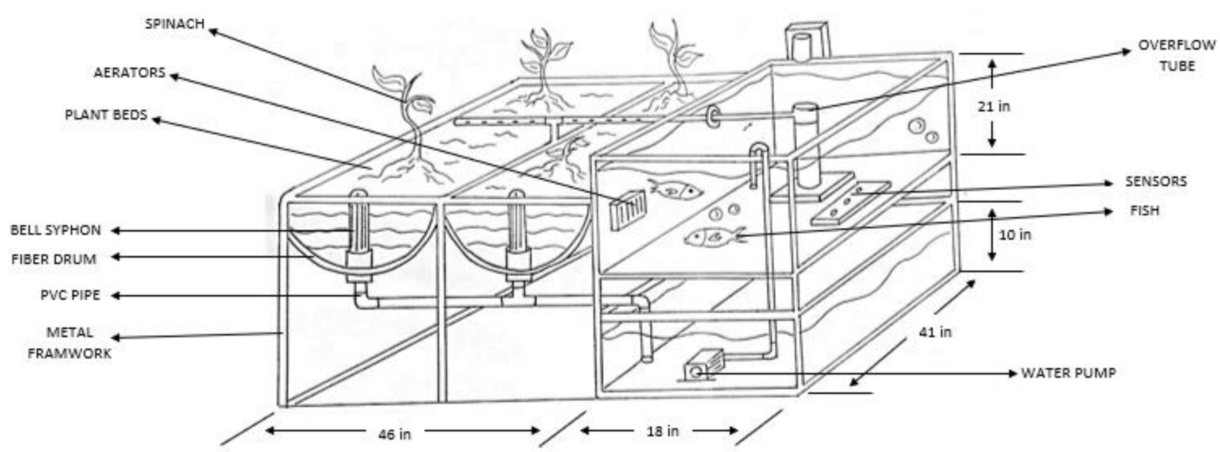
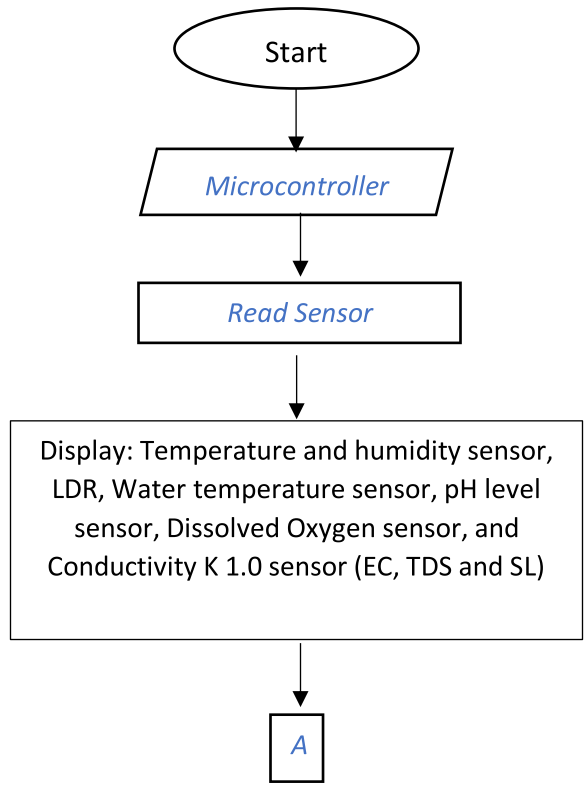


Figure 3.5 Designed Aquaponics System Set-up


Start
Microcontroller
Read Sensor
Display: Temperature and humidity sensor, LDR, Water temperature sensor, pH level sensor, Dissolved Oxygen sensor, and Conductivity K 1.0 sensor (EC, TDS and SL)
A

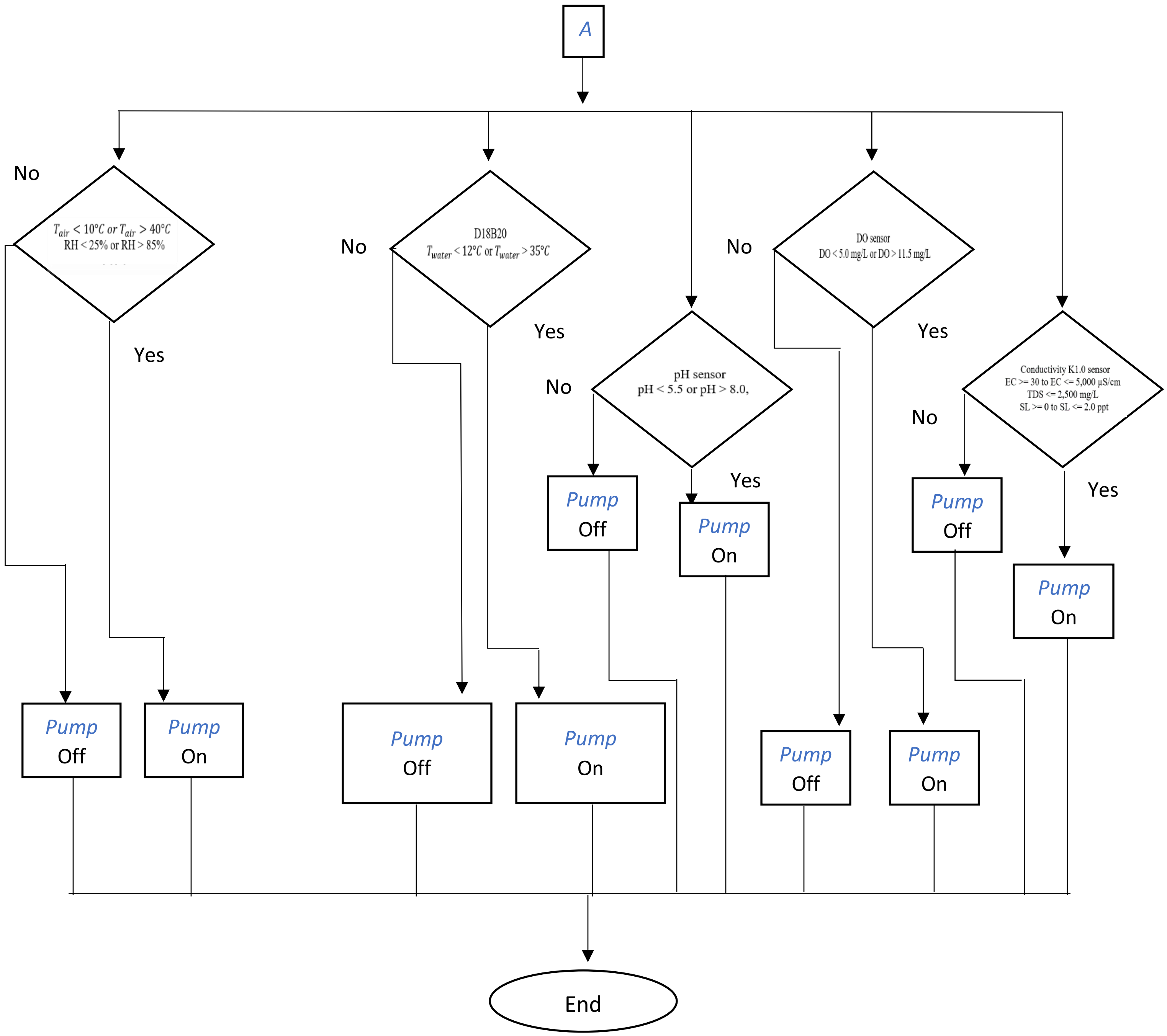


Figure 3 .5 Flow chart of Monitoring and Control of Aquaponics system

Water Quality is important for the Aquaponics system to be habitable. Water Level, Temperature of Water, Dissolved Oxygen, Electrical Conductivity, Total Dissolved Substance, and Salinity is needed to be regulated in the tank; while the Air humidity, Soil Humidity, Air Temperature is also considered in the plant beds. In order to monitor these parameters, multiple sensors are used and recorded through LabView. DHT11 sensor is used to determine the temperature and humidity, D18B20 sensor for the water temperature, pH sensor circuit for the pH of water, Dissolved Oxygen sensor for the oxygen level, and Conductivity K 1.0 sensor used to determine the total dissolved substance, electrical conductivity and salinity. Microcontroller is used to control the Water pump and Aerators. The water quality parameters of the aquaponics system such as water pH level, dissolved oxygen level, electrical conductivity, total dissolve solids and salinity, are controlled and monitored to maintain the best growth conditions of the fish in the aquaculture tank and the plants on the hydroponic beds. The set range for the water temperature (T_{water}) is $16\ to\ 33°C$ [33]; The tolerance range of pH level for most plants is 5.5 to 8.0 pH [34]; The acceptable level of Dissolved Oxygen is set from DO >= 5.0 to DO <=11.5 mg/L [30]; The set range of electrical conductivity is from Electrical Conductivity >= 30 to EC <= 5,000 µS/cm; The normal value of Total Dissolved Substance is set to TDS <= 2,500 mg/L [35]; the set range of salinity is SL >= 0 to SL <= 2.0 ppt [36]; Water pump and Aerator will be active if the set parameters are not followed. This will be observed every minute. Data every hour will be listed in the table. Through LabVIEW, using the recording function feature of LabVIEW software we can also view the previous data recorded.

Table 3.1 Aquaponics Parameters

Time	Water Quality Parameters							Environmental Parameter		Actuator Status	
	Water Level (cm)	T water (℃)	DO (Mg/L)	pH	EC (uS/cm)	TDS (mg/L)	SL (ppt)	RH (%RH)	Temp. Air (℃)	Water Pump	Aeration Pump
1:00											
2:00											
3:00											
4:00											
5:00											
6:00											
7:00											
8:00											
9:00											
10:00											
11:00											
12:00											
13:00											
14:00											
15:00											
16:00											
17:00											
18:00											
19:00											
20:00											

3.1.2 Smart Switching System

The designed Smart switching System consists of Arduino microcontroller, Signal Processor, and 2 Relays. The microcontroller output signal is used for making switch of load supply between Grid and Solar PV/Battery. Transistor is used for the relay triggering which results change of power supply from one source to another. The supply from the Grid will feed the load system with relay being on OFF state however, there is enough power detected from the solar PV source there will be a change of supply from the grid to PV/Battery source hence relay being in ON position. The smart controller can control all the continuing operation within the system and make appropriate decision for the energy saving of the grid. The microcontroller is programmed to monitor the battery's percentage level of charge. It identifies the condition of the batteries whether its low, enough fully charged. The dependency of the system relies on the status of the battery. If the battery status has reach below 50%, the microcontroller function to switch the systems source to grid and at the same the PV installation will change its battery till ready. If the current battery status is above 50%, the systems will be dependent on the stored energy and at the same time the collected energy from the photovoltaic installation will be reverted to the utility. The operation of the Smart switch is to be observed for 30 days.

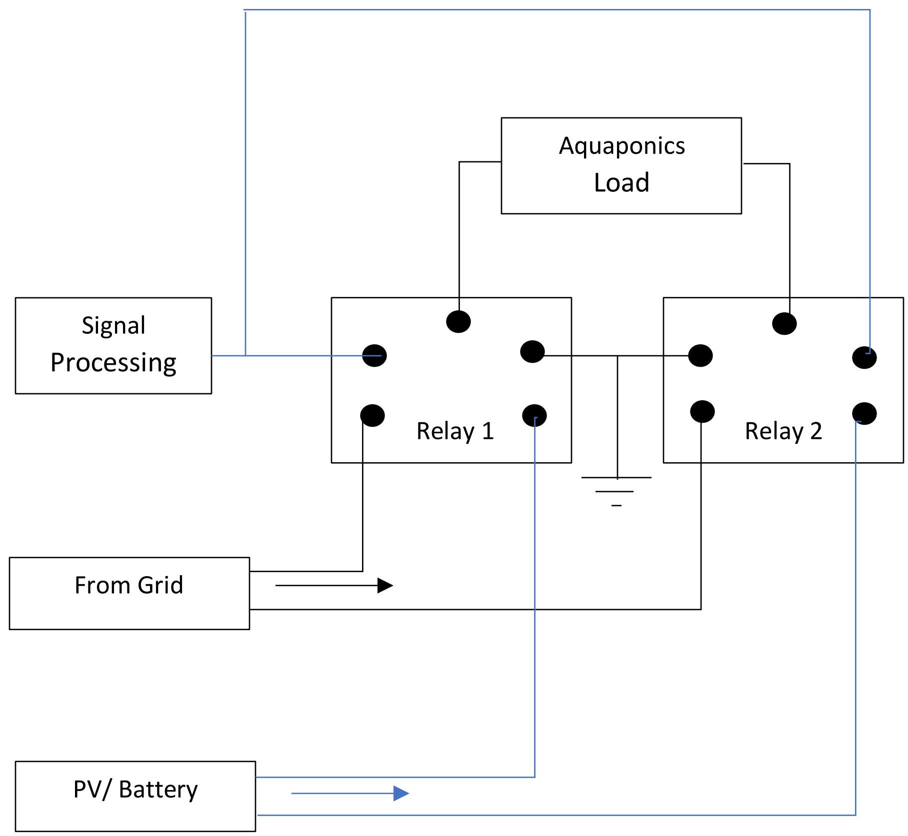


Figure 3.7 Circuit diagram of Smart switching Supply Selection unit

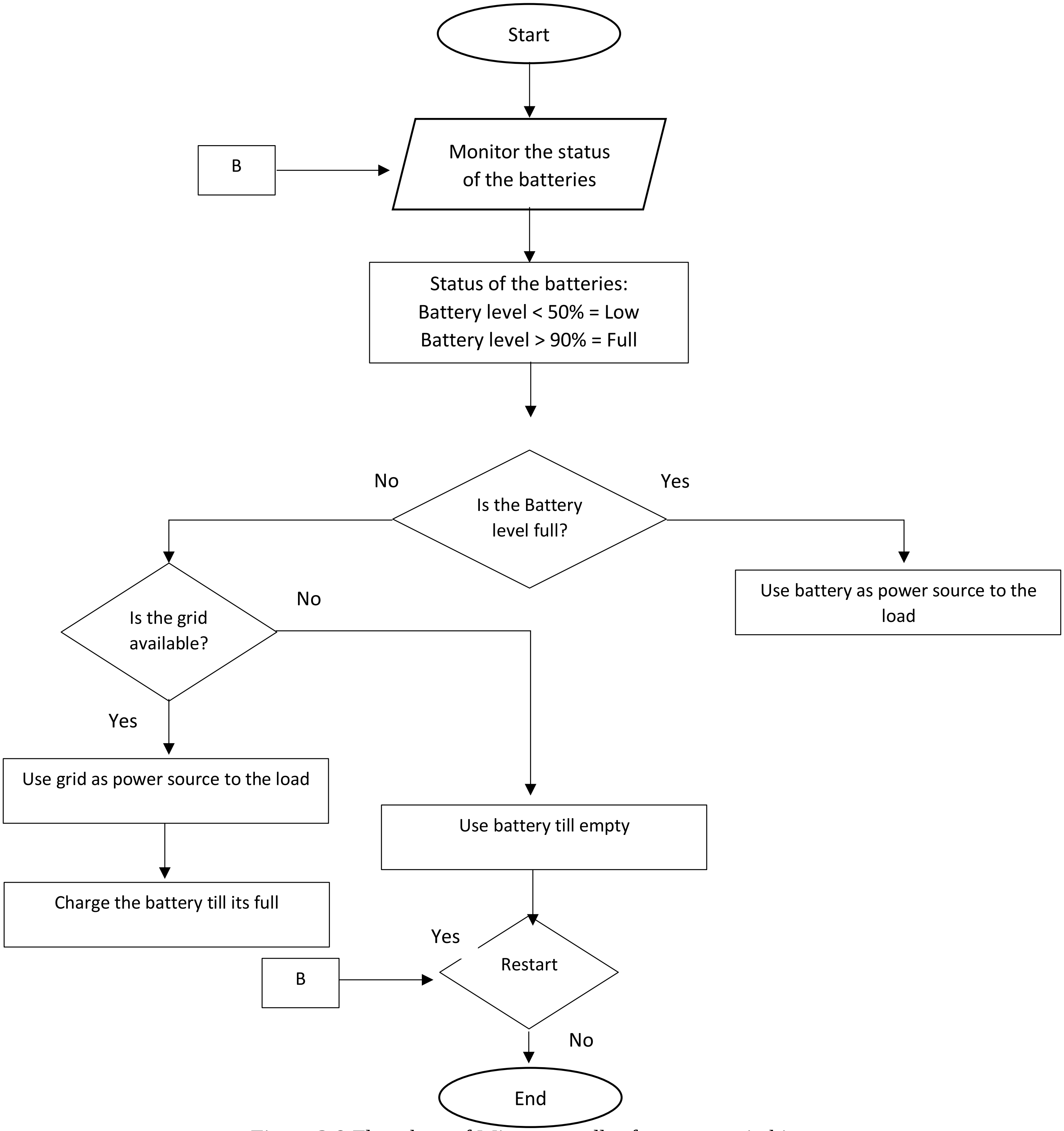


Figure 3.8 Flowchart of Microcontroller for smart switching

As the microcontroller is programmed to monitor the status of the battery, in this table we are going to record the battery level and status of battery and photovoltaic system to know the power source used in the aquaponics system. The operation of smart switching is observed in 30 days and data are gathered through LabVIEW software. Through LabVIEW, using the recording function feature of LabVIEW software we can also view the previous data recorded.

Table 3.2 Smart Switching

DAY	Battery Level (% Charged)	Status of Battery (Full or Low)	Status of Photovoltaic System	Power Source in use (Grid/PV system)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				

28				
29				
30				

3.2 Compare the Integrated Aquaponics System to the Related Research

There are differences between the developed and related research, but its functionality remains constant. Since the research of Nagayo is suited to function with reference to their country's climate, the developed integrated system is adjusted suitable to ours, Philippines. There are differences between the integrated system and Nagayo's system, yielding a power consumption difference. In order to compare performance, the total power consumption for the integrated systems must be determined and compare it to the related research's stated power consumption. Power consumption is already measured using the LabView every minute. Power consumption data is to be recorded in the table every 3:00pm of the day for 30 days. Through LabVIEW, using the recording function feature of LabVIEW software we can also view the previous data recorded.

Table 3.3 Total Power Consumption of an Integrated and Typical Aquaponics System

DAY	Power Consumption (kW)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	

12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	
	TOTAL=

3.3 Determining the Total Energy Reverted back to the Grid

Aerators and pump will only be active sensors detected violation with the limits thus there will be a time the aquaponics will not consume power. Having a solar PV system, the application of net metering in the automated aquaponics system is very significant to the study. By the usage of bidirectional meter which indicates power usage and excess power produced. The excess power not used by the Aquaponics system is reverted to the electric grid which will also be observed by the LabVIEW. Every 1500 hour of the day the excess reverted is to be measured this is to be repeated for 30 days. Through LabVIEW, using the recording function feature of LabVIEW software we can also view the previous data recorded.

Table 3.3 Net metering applied in Aquaponics system

DAY	TOTAL REVERTED POWER (kW)
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	
11.	
12.	
13.	

14.	
15.	
16.	
17.	
18.	
19.	
20.	
21.	
22.	
23.	
24.	
25.	
26.	
27.	
28.	
29.	
30.	
	TOTAL=

Monitoring the quality of energy that is reverted shows the effectiveness of the PV system's design in power systems. Parameters like current, voltage, frequency are considered to measure in order to know if the reverted power will sync with the grid system; furthermore, within the standards of the Philippine Grid Code. Monitoring of the energy produced by the system is observed for 24 hours in 30 days. These parameters are monitored in real time by LABVIEW and the record average consumption every hour. Complete data will be seen in NI LabVIEW GUI monitoring system. Through LabVIEW, using the recording function feature of LabVIEW software we can also view the previous data recorded.

Table 3.4 Monitoring of Energy Quality (Reverted)

Day 1/30 Starting at 1am

Trials (Hour)	Current (A)	Voltage Variation (V)	Frequency (Hz)	Total Harmonic Distortion (Hz)	Power Factor (%)
1:00					
2:00					
3:00					
4:00					
5:00					
6:00					
7:00					
8:00					
9:00					
10:00					
11:00					
12:00					
13:00					
14:00					
15:00					
16:00					
17:00					
18:00					
19:00					
20:00					
21:00					
22:00					
23:00					
24:00					

3.4 Growth Performance of the Fish and Plants

3.4.1 Growth Performance of the Fish

In the Aquaponics system the growth performance of the fishes is observed within 100 days every 3 days. The growth rate (g day^{-1}) can be easily calculated fitting exponential model, using only the initial and final weight during the period considered necessary, however it is not recommended for a long period of time [29]. Growth rate is not constant but modifies throughout the growth period. The expected daily weight gain of a Tilapia is 1.013/day in its first 30 days, 2.682g/d for the next 30 days, and 3.030g/day in the 100^{th} day of living [30]. Height and weight of the fish are to be considered to test the effectiveness of the system.

When determining the maximum number of tilapia fingerlings to put in an aquaponics system, only consider the gallons of water available to the fish for swimming. The general consensus is that a pound of tilapia will need 3 gallons of water. A full-grown tilapia will weigh approximately 1 pound although they can grow larger. This may mean you only have 1 tilapia per 3 gallons [19].

$$\frac{1\ pound\ of\ Tilapia}{3\ gallons\ of\ water} = \frac{Population\ of\ Tilapia\ in\ the\ Aquaculture\ tank}{75\ gallons\ of\ Water}$$

Population of Tilapia in the Aquaculture tank = $25\ Tilapia\ Fingerlings$

In measuring the fish total weight, get a certain number of fish and put it carefully in the container with clean water. Weigh first the container with water and record this as the initial weight in the spring balance. Use a spring weighing balance to weigh the container with a fish and water inside by hanging it to the weigh balance, do it as quickly as possible. Record the gathered parameters every three days of measurement. The total weight that a spring balance will give is the gross weight which is the total weight of the water, container and the fishes. To determine the individual fish weight simply subtract gross weight with the initial weight of the container with water and then divide it with the total with the number of fishes inside the container and you will get the average weight gained by the fish.

The absolute growth rate (AGR) within 30 days, 60 days and 100 days of each family was calculated based on the following formula

$$AGR\ (g \cdot d^{-1}) = (W - W_0)/(t - t_0)$$

In terms of measuring the length of the fish. Set-up the aquarium by attaching a fixed flat ruler graduated in millimeters and centimeters in every side of the aquarium. Use these rulers when the fish stops beside it by capturing a camera. Use the camera to examine the captured photo by zooming in so that you can get the perfect length of the fish. Record the gathered data in a paper.

Days	**Fish**		
	Length of Fish (mm)	**Weight of Fish (g)**	**Quantity of Fish (pieces)**
1			
4			
7			
10			
13			
16			
19			
22			
25			
28			
31			
34			

37			
40			
43			
46			
49			
52			
55			
58			
61			
64			
67			
70			
73			
76			
79			
82			
85			
88			
91			
94			
97			
100			

3.4.1 Growth Performance of the Plant

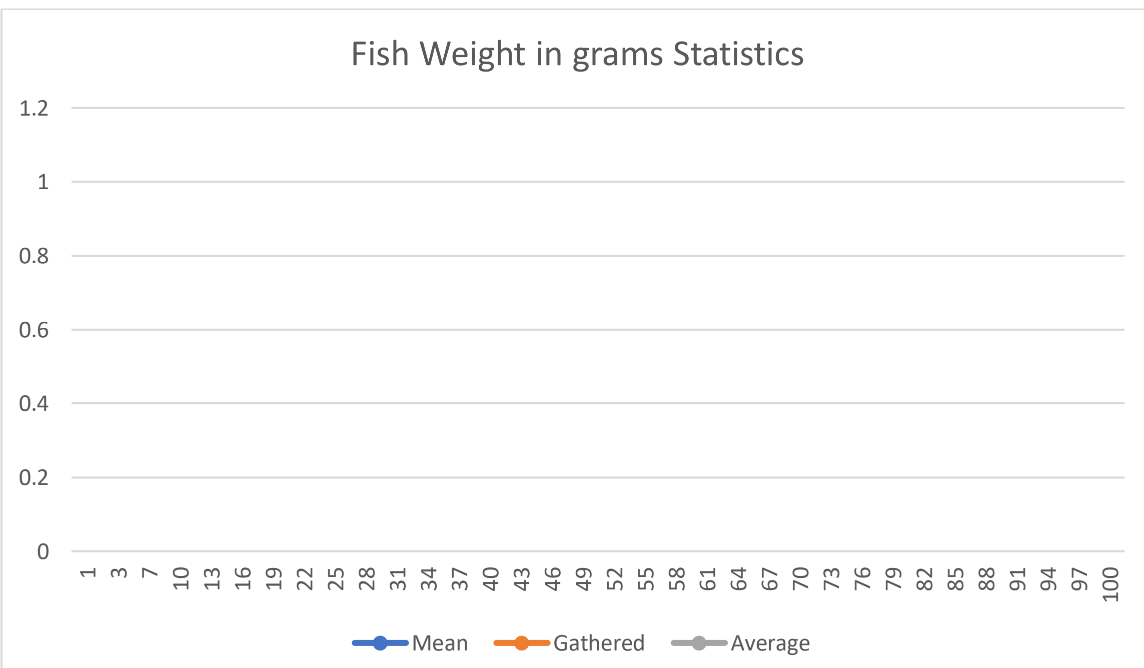
In the Aquaponics system the growth performance of the plant is observed in six weeks. Seed will germinate in 5-14 days depending on the variety and growing condition. Fertilize the spinach only if the growth rate is slow. The Average daily growth rate of a Spinach is not constant and its growth rate is 1.92cm/d after the plant starts to produced leaves. [31]. The estimated time for the Spinach to be harvested is 37-45 days after it was planted. To harvest the spinach, you must achieve its leaves length of approximately 4-6 inches and a leaf number of 5-6 pieces [32]. While for the plants, Length of the stem and total number of leaves are to be considered. By using a measuring tape, measure the length of the leaves and then record it on a paper. You can also use a graphing paper for measuring its length. After measuring the leaves lengths, count the number of leaves of the plant and also record it on the table.

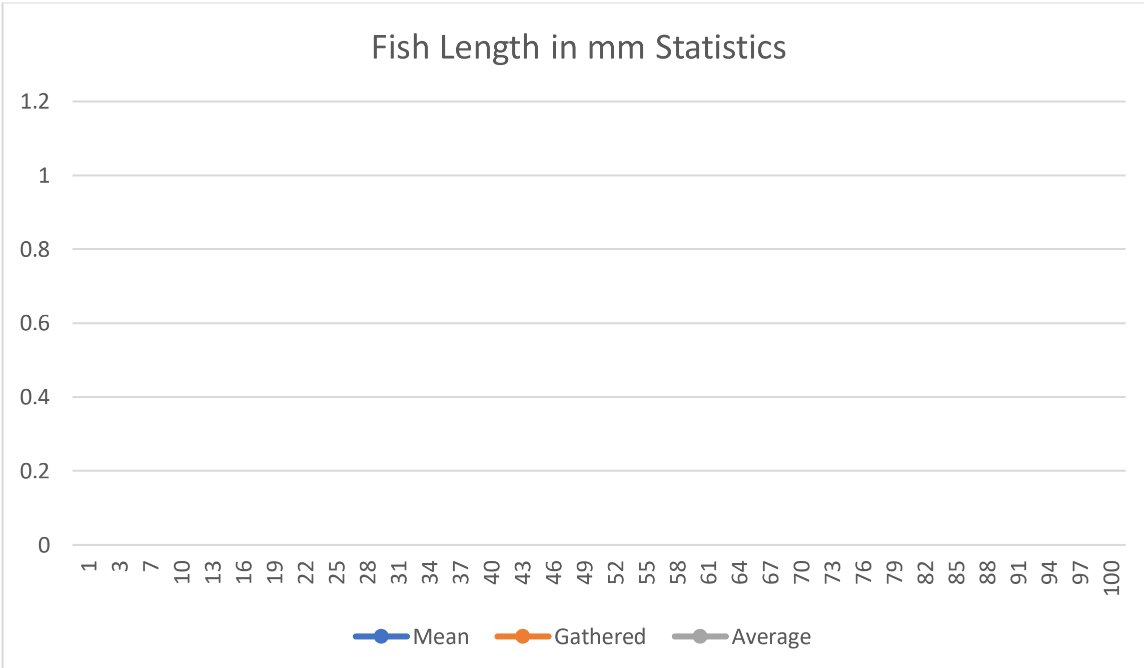
Total number of plants in grow bed can be determine using ratio of fish weight and the grow bed. 500 grams of fish for every 0.1 square meter of grow bed surface area [33].

$$41inx46in = 1.2\ square\ meter$$

$$\frac{500 grams\ of\ Fish}{0.1\ sq.m\ of\ grow\ bed} \text{ x } \frac{1.2 sq.m\ of\ grow\ bed}{350\ grams\ of\ fish} = \text{17 pieces of spinach}$$

	Plant	
	Length of Stem (cm)	**Numbers of Leaves (piece)**
3		
6		
9		
12		
15		
18		
21		
24		
27		
30		
33		
36		
39		
42		
45		




Fish Length in mm Statistics
1.2
1
0.8
0.6
0.4
0.2
0
1
3
7
10
13
16
19
22
25
28
31
34
37
40
43
46
49
52
55
58
61
64
67
70
73
76
79
82
85
88
91
94
97
100
Mean
Gathered
Average

STATISTICAL TREATMENTS

One Sample T-test (For the Tilapia)

T-distribution is to be use because the population standard deviation is unknown and is now a value must estimate. According to research, the growth of the Tilapia expected within 100 days is 300.04±58.40 g. This data will be the refence of comparing the average weight of the Tilapia of Aquaponics and be use as the sample mean. The observation period of the fishes will be conducted for 100 days. For every three days growth is to be observe and recorded in the table. After the 100 days of observation all the weight of the Tilapia is to be averaged and the value will be use as the population mean. 25 fishes is to be observe. As stated, standard deviation is assumed 20 and alpha = 0.05

1. Define Null and Alternative Hypotheses

   $H_o = \mu = 300.04 \pm 58.40$

   $H_1 = \mu \neq 300.04 \pm 58.40$

2. State Alpha

   $\alpha = 0.05$

3. Calculate the Degrees of Freedom

   Degrees of Freedom=No. of Fishes – 1= 25-1 = 24

4. State Decision Rule

   Using the 24 as our Degrees of Freedom and $\alpha = 0.05$, critical values can be found in the T-table, in which in this case is ±2.064

5. Calculate Test Statistic

Formula = $t \ = \frac{x-\mu}{s_x}$; where $s_x = \ {}^{s}/_{\sqrt{n}}$

Where s_x = Estimated Standard Error of the mean

s = Sample Standard Equation

n = Sample Size (No. of Fish)

x = Sample mean (Average Weight of Fish (research))

µ = Population mean (Average weight of Fish (actual))

6. State Results

If *t* is less than -2.064 or greater than 2.064, reject the Null Hypothesis

If *t* is greater than -2.064 or less than 2.064, reject the Alternative Hypothesis

7. State Conclusion

The Designed Aquaponics System is an effective agricultural cultivation

The Designed Aquaponics System is not an effective agricultural cultivation

One Sample T-test (For the Spinach)

T-distribution is also to be use because the population standard deviation is unknown and is now a value must estimate. According to research, the growth of the Spinach expected within 37-45 days is expected to be 4-6 inches of leaves. This data will be the refence of comparing the average length of the leaves and be use as the sample mean. The observation period of the plant will be conducted for 6 weeks. For every three days growth is to be observe and recorded in the table. After 6 weeks of observation all the length of the Tilapia is to be average and the value will be use as the population mean. 17 plants is to be observe. As stated, standard deviation is assumed 20 and alpha = 0.05.

1. Define Null and Alternative Hypotheses
    i. $H_o = \mu = 5$
    ii. $H_1 = \mu \neq 5$
2. State Alpha
    i. $\alpha = 0.05$
3. Calculate the Degrees of Freedom
    i. Degrees of Freedom=No. of Plants – 1= 17-1 = 16
4. State Decision Rule
    i. Using the 16 as our Degrees of Freedom and $\alpha = 0.05$, critical values can be found in the T-table, in which in this case is ±2.120

5. Calculate Test Statistic

   i. Formula = $t = \frac{x-\mu}{s_x}$; where $s_x = s/\sqrt{n}$

Where s_x = Estimated Standard Error of the mean

s = Sample Standard Equation

n = Sample Size (No. of plants)

x = Sample mean (Average length of leaves (research))

μ = Population mean (Average length of leaves (actual))

6. State Results

   i. If *t* is less than -2.120 or greater than 2.120, reject the Null Hypothesis

   ii. If *t* is greater than -2.120 or less than 2.120, reject the Alternative Hypothesis

7. State Conclusion

   i. The Designed Aquaponics System is an effective agricultural cultivation

   ii. The Designed Aquaponics System is not an effective agricultural cultivation

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