

2023-06

# Development of intelligent hybrid power transfer switch to support optimization of water supply scheme: case of Arusha

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<https://doi.org/10.58694/20.500.12479/2128>

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**DEVELOPMENT OF INTELLIGENT HYBRID POWER TRANSFER  
SWITCH TO SUPPORT OPTIMIZATION OF WATER SUPPLY  
SCHEME: CASE OF ARUSHA**

**Adol Dominic Majak Deng**

**A Project Report Submitted in Partial Fulfilment of the Requirements for the Degree of  
Master of Science in Embedded and Mobile Systems of the Nelson Mandela African  
Institution of Science and Technology**

**Arusha, Tanzania**

**June, 2023**

## **ABSTRACT**

Water demand and energy usage are inextricably related in water supply systems, because using, distributing, and extracting water requires a lot of energy. Any improvement in the scheme's energy conservation, particularly pumping conservation, results in a significant reduction in total operating costs. This necessitates the development of methods for analyzing and optimizing systems that consume electrical energy, which are typically more complicated than traditional water systems. Previous techniques had a narrow scope and could not be applied to all sorts of water supply plan designs and systems. This study explored the viability of adopting an intelligent hybrid power transfer switch system to mitigate high energy consumption, and so forth, in order to improve the operation of the Ngaramtoni Water Supply Scheme, located in Arusha Tanzania. This system detects, transmits, and receives water level data through an algorithm that is intelligently programmed to switch to the necessary power source (solar or grid), and it also has additional features like an automatic transfer switch in the event of a power cut or signal failure and, user safety mode among others. Wi-Fi is used for output parameters monitoring, while LoRa is used for communication. The power source input into the pump controller is controlled by the system. The data obtained during the experiment demonstrates the system's effectiveness and capabilities in terms of switching mechanisms, water level detection and transmission, data retrieval from the ESP32-WROOM-32 microcontrollers via Wi-Fi and a communication module PZEM-04T-V3.0, and visualization using the Blynk app and a Liquid Crystal display.

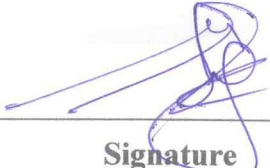
## DECLARATION

I, Adol Dominic Majak Deng, hereby declares to the Senate of the Nelson Mandela African Institution of Science and Technology that, except where otherwise stated, this project report is the result of my own original research or work, and it has not been submitted for degree consideration at this or any other institution.

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## CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by The Nelson Mandela African Institution of Science and Technology, a project report titled ***“Development of an Intelligent Switching of Hybrid Power System for Optimization of Water Supply Scheme, Arusha”*** in partial fulfilment of the requirements for the degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology.

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## **ACKNOWLEDGEMENTS**

First and foremost, I thank the Almighty God for his mercy and blessings during my project and dissertation, which has led to its successful conclusion.

Second, I would like to express my gratitude to Prof. Hans Komakech the WISE – Futures' Centre Leader, as well as my supervisors, Dr. Devotha Nyambo, and Dr. Mussa Ally, for their advice, support, and mentorship during the project.

Third, I would like to thank and express my heartfelt appreciation to The Nelson Mandela African Institution of Science and Technology (NM-AIST) and the School of Computational and Communication Sciences and Engineering (CoCSE) for providing resources particularly the laboratory, which made my project much easier.

Fourth, I would like to thank my academic sponsor "The Center of Excellence for ICT in East Africa" (CENIT@EA) and the industrial attachment firm "Water Infrastructure and Sustainable Energy Futures" (WISE – Futures) for their support during the project.

Finally, I am really grateful to my friends and family for their encouragement and support in many ways, both direct and indirect.

## **DEDICATION**

First and foremost, I would like to dedicate this Final year project work to my adoring, sweet, and lovely parents for their prayers, faith, support, and constant encouragement to achieve my dreams. Thank you for teaching me to believe in myself, in God, and in my dreams.

Secondly, I would also like to extend my gratitude to my supervisors for their humble effort towards their supervision, and encouragement that they put to show the path towards my dreams as well as the completion of this project report.



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## LIST OF ABBREVIATIONS

AC	Alternating Current
AP-MODE	Adaptive Parallel Multi-Objective Differential Evolution
ATS	Automatic Transfer Switch
AUWSA	Arusha Urban Water Supply and Sanitation Authority
CPU	Central Processing Unit
DC	Direct Current
DFID	Department for International Development
EKTS	Electric Control Techniques Simulator
EPANET	Environmental Protection Agency Network
FCDO	Foreign Commonwealth Department Office
FCO	Foreign Commonwealth Office
GA	Genetic Algorithm
HRES	Hybrid Renewable Energy System
HVAC	High Voltage Alternating Current
ICT	Information and Communication Technology
IoT	Internet of Things
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LoRa	Long Range
MCU	Microcontroller Unit
MO	Manual Override
NC	Normally Closed
NO	Normally Open
NSGA	Non-Dominated Sorting Genetic Algorithm
RO	Reverse Osmosis
VPS	Variable Power Supply
Wi-Fi	Wireless Fidelity

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background of the Problem

Significant amount of energy today is consumed by the water supply systems, which is spent at each stage of the water production and supply chain, beginning with extraction of raw water from the boreholes or other water sources to the treatment plant, while the water is being treated and distributed across the network.

Energy is wasted due to a variety of factors, including poor design, improper installation or maintenance, inefficient pump stations, aging pipes with significant head loss, bottlenecks in the supply network, excessive supply pressure, and inefficient supply facility operation techniques. Another major source of energy waste is surplus supply caused by water leaks or improper water use. When it is revealed that the average global water loss is 30%, the same percentage of energy is consumed as well said Feldman (2009). He also added that considering the aforementioned issues, energy consumption savings could amount to 20% - 30% of present use.

The study was done at the Ngaramtoni Water Supply Scheme as a representative of other numerous water systems in developing countries. The Ngaramtoni Water Supply Scheme was constructed to provide high quality and sufficient drinking water to five villages and Ngaramtoni town. The scheme which uses the Reverse Osmosis (RO) system to treat groundwater and spring water is operated by Arusha Urban Water Supply and Sanitation Authority (AUWSA). Its operation is not optimized leading to very high running costs. Specifically, the scheme is currently not able to recover its operation costs. To be able to operate sustainably, there is a need to develop an optimal operational protocol of the Ngaramtoni water systems. The scheme has two treatment plants for reverse osmosis (RO). One plant is at ASA-Farm and the other is at the Hazina site in Arusha Tanzania. Both plants are expected to yield 60 m<sup>3</sup>/h high quality drinking water (i.e., fluoride level below 1.5 mg/L) at their best. The ASA-Farm treatment plant uses raw water from two boreholes that uses a pumping mechanism which contributes a total of 72 m<sup>3</sup>/h from two pumps each at 36 m<sup>3</sup>/h. The treatment Plant at Hazina uses raw water from the Emuroto spring source with the capacity to transfer by gravity 72 m<sup>3</sup> per hour to the plant via a 135 m<sup>3</sup> collector tank. Treated water from Hazina plant feeds the Olkokola, Lengijave and Lemoja distribution tanks with capacities



of 300 m<sup>3</sup>, 450 m<sup>3</sup>, and 300 m<sup>3</sup>, respectively as in Fig. 1. The ASA-Farm treatment plant also supplies water to Lemoja with a capacity of 300m<sup>3</sup> which then feeds Ekenywa and Kilimapunda (Ngaramtoni) distribution tanks plus the Seuri domestic points as shown in Fig. 1. Lemoja tank is therefore fed by both treatment plants but there are no records indicating the percentage contributed by each plant.

A feasible approach for overcoming some of the aforementioned essential obstacles and supporting the optimization process is to intelligently and automatically control the power sources linked to the booster pumps. This suggested system determines whether the required energy source is battery-less solar energy or grid energy based on the data obtained from the water level sensor at that moment. Furthermore, as shown in Table 3, this system includes ESP32-WROOM-32 Microcontroller modules, LoRa Ra-01 433 MHz communication module, an ultrasonic sensor for data collecting, AC communication module PZEM-04T-V3.0, AC/DC Relays, power indicators, selector switches, and AC contactors, power failure relay as the major components. As a result, a water level detection system is designed and developed to capture water level data based on the requirements of the main proposed system for its full operation as intended.

However, in an intelligent mode, the battery-less solar energy will be use as the priority and grid energy as an alternative except when a prolong unreliable solar energy or unsuitable weather conditions for the solar panel energy production occurs. And grid energy will only be used whenever the water level in the tanks (Lemoja tanks) is at low levels. Meaning, even if the water level in the tank (Lemoja tank) is moderate or high, the grid energy will not be switched on except if the system is to be operated manually. In addition, the use of water loggers in Lengijave and Olkokola tanks will be to control the opening and closing of the valves located at the water distribution points between Lengijave and the Spring Reverse Osmosis (RO) and this will increase the water in Lemoja tank and hence the constant use of solar energy for booster pumps operation.

Therefore, this proposed method will significantly increase the energy efficiency and generally optimize the energy consumption and manual power selection of the booster pumps of the Ngaramtoni Water Supply Scheme. The systems will also be automated to eliminate user interaction, cost-effective with the use of renewable energy, integrated with the Internet of Things (IoTs), user-friendly, and secure, among other things.

## **1.2 Statement of the Problem**

The Ngaramtoni Water Supply Scheme which was constructed using the funds from the Department for International Development (DFID) which closed on the 2 September 2020 and merged with Foreign Commonwealth Office (FCO) to create Foreign, Commonwealth Department Office (FCDO) as said by Prime Minister's Office *et al.* (2020) and currently being operated by Arusha Urban Water Supply and Sanitation Authority (AUWSA) needs optimization. The scheme has a lengthy history. The data in Figure 2 shows that there are some substantial operating costs since the cost of running the water supply system is not covered by the way it is now run. The data analysis done at the side reveals that the system's inability to be controlled optimally, specifically the lack of optimal pump scheduling to reduce energy consumption, the absence of monitoring systems to track the condition of water distribution channels, the necessary number of consumers as well as the amount of water to be supplied based on consumption rate, insufficient pump energy management, which contributes to high energy usage, and some human factors such as manually turning on and OFF pump systems, measuring energy and water usage, etc., are all factors that contribute to the failure to control the system optimally. Currently, this water supply scheme's operation is occasionally done at random. For instance, the operators manually turn on and OFF the booster pumps and turn on the power source, such as grid energy or battery-less solar energy, based on visual observations of the water levels in the tanks (such as the Lemoja tank). As a result, the operation needs to be optimized by system centralization and automation. Therefore, the proposed system will rely on both hardware and software to perform its tasks and support the scheme's optimization process.

## **1.3 Rationale of the Study**

As mentioned in the problem statement, The Ngaramtoni Water Supply Scheme is currently facing very high operation costs which are largely contributed by the failure to optimally control the system; that is to say, lack of monitoring systems to monitor the state of water distribution channels, the required number of consumers as well as quantity of water to be supplied based on the consumption rate and some human factors due to manual operation and control which also results in high energy consumption. As a result, the motive for this is that the optimization strategy proposed to tackle this problem would be cost-effective with the use of renewable energy, automated to minimize human interference, user friendly while still taking high levels of safety into account, and so on. And the innovation behind this proposed

system is that it will rely on the detection of water levels from the water tanks (Lemoja water tank) to control the use of energy with battery-less solar energy as the priority to power the booster pumps because they are the system's largest energy consumers. Furthermore, the clean water from Hazina will be controlled using automated valves at the distribution points and channeled to Lemoja tank with the help of water level detection data from Lengijave and Olkokola tanks to be received by the junction valves control system automatically.

## **1.4 Objectives of the Study**

### **1.4.1 General Objective**

To develop an intelligent hybrid power transfer switch to support optimal operation of water supply scheme.

### **1.4.2 Specific Objectives**

The project had the following research objectives:

- (i) To study, analyze and set up the requirements and specifications of the intelligent hybrid power transfer switch.
- (ii) To integrate the designed and developed system requirements for the intelligent hybrid power transfer switch.
- (iii) To validate the intelligent hybrid power transfer switch system.

## **1.5 Research Questions**

The project aimed to answer the following research questions:

- (i) Is studying, analyzing, and establishing system requirements and specifications a vital component of an intelligent hybrid power transfer switch system development?
- (ii) Is the integration of system designs and system requirements a key component of achieving a system's goal?
- (iii) Could the validation results of this intelligent hybrid power transfer switch system demonstrate the system's cost effectiveness and implementation?

## **1.6 Significance of the Study**

The importance of this project arises from its practical contribution to the water supply scheme sector and hybrid power systems in terms of reducing system running costs by optimizing energy use. This effort, on the other hand, contributes to a theoretical approach of intelligence in transferring energy sources alternately over vast distances using wireless data transmission. In addition, this project uses sensors to detect water levels and monitor energy consumption, and it is designed to work both automatically and manually in the case of a data or signal breakdown in the system.

## **1.7 Delineation of the Study**

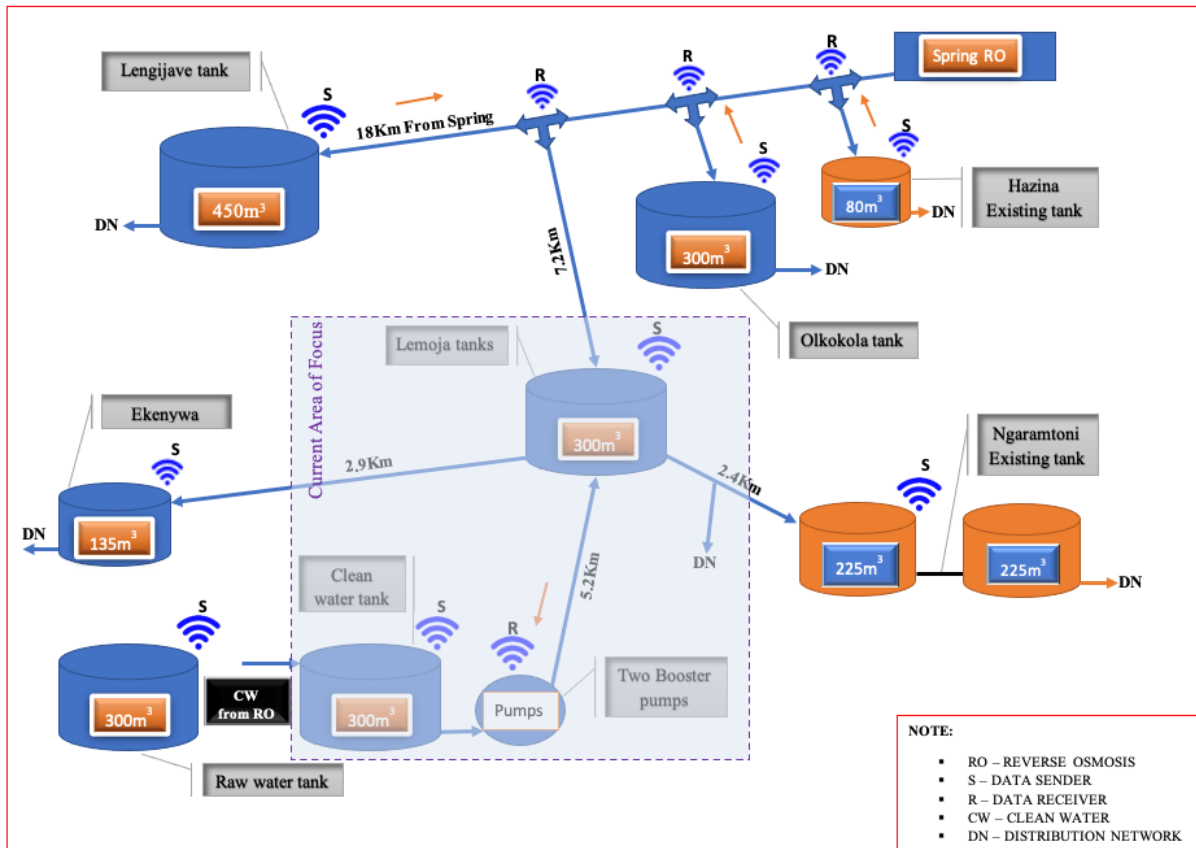
The goal of this project is to improve the Ngaramtoni Water Supply Scheme's operation, particularly in terms of energy consumption and human interaction. The water level measurement technique was used in the project to intelligently switch or alternate (switch) between the two energy sources (grid and solar), with solar energy being prioritized to reduce grid energy consumption. However, LoRa was used for wireless data transfer for this process to succeed. Furthermore, to account for data transmission or water level system failure while limiting human interaction, the system can be switched to automatic or manual mode configuration. This project also considered grid energy consumption monitoring techniques, which were implemented using an LCD and the Blynk application via Wi-Fi.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 About Arusha City

Arusha is an important international, diplomatic, tourism, and regional center. Its water and sanitation system are insufficient and urgently needs to be improved. Despite having the greatest water connection density per kilometer of water distribution pipeline among all regional utilities in the country, water access coverage in the city is only approximately 44% as per African Development Bank Group (2015). However, the electrical energy usage for water treatment, distribution, and extraction are currently high due to the high demand of water and systems usage. Furthermore, since Arusha was elevated to city status in 2010, the AUWSA service area has nearly quadrupled from 93 km to 208 km (African Development Bank Group, 2015). In this context, the Tanzanian government, through the Ministry of Water (MoW), presented a project application to the African Development Bank (AfDB) for finance assistance to support the extension and upgrade of a water and sanitation project in Arusha. As a result, the main goal of the proposed project is to reduce excessive energy usage in order to promote the optimization of the Ngaramtoni water distribution network in Arusha. The installation of this project will relieve the City's present water supply issues in that area. Figure 1 shows the Ngaramtoni water distribution network.



**Figure 1: A conceptual framework (block diagram highlining the area of focus)**

Figure 1 depicts the conceptual framework of the complete Narration water supply network, including the optimization plan and the present area of attention, as suggested by the title of this research. However, just a few measurements are shown, specifying the distances between the water tanks and the water sources, which include Hazina spring water and ASA-Farm boreholes.

## 2.2 Related Works

According to Al-Ani *et al.* (2013), a study known as "The Adaptive Parallel Multi-objective Differential Evolution (AP-MODE) heuristic algorithm" was proposed, which is developed and used for: (a) choosing the least expensive or ideal pump combinations in water distribution systems (i.e., optimal pump scheduling); (b) assessing the total energy costs needed to run the network; and (c) figuring out the reservoir storage capacity (i.e., It is a cutting-edge tactic that can save operational expenses, optimize energy use, and reduce utility bills.

The paper presents a framework for holistic analysis and optimization of water supply and distribution systems that use alternative water sources. It includes variables for both design and

operational decision making, water and energy infrastructure, system simulation, analysis of constraints and objectives, and policies and regulations that may affect any of these factors said Blanco *et al.* (2017). However, this framework will enable users to conduct a thorough analysis and/or optimization of their water supply system, considering multiple types of water sources and consumers, the impact of their design and operational decisions, as well as the impact of government policies and different energy supply options. The framework is illustrated by two case study systems: the first is a harvested stormwater system that is used to demonstrate the importance of simulation and analysis before optimization, and the second uses four different water sources to boost security supply and was optimized to reduce pump energy use.

Bolognesi *et al.* (2014) were investigating the possible optimal network configurations that minimize energy consumption and maximize energy efficiency while acting on the system's main structural parameters (pipe diameters, leakage rate) and taking pump efficiency into account. The optimization process is carried out by combining the heuristic algorithm GHEST with the EPANET solver and applying it to a synthetic case study from the literature.

Byeon *et al.* (2015) explores the popularity of putting the Smart Water Grid idea into action on Yeongjongdo Island, that is home to Korea's main airport. This innovative idea is based on connecting variety of water resources optimizing their management with novel information technology solutions. Water generated by rainfall, external water resources (i.e., metropolitan water distribution system), gray water, and other types of alternative water resources are all integrated into the proposed system. The paper investigates the feasibility of this approach and the interest in the Smart Water Grid concept.

A study done by Chang *et al.* (2018) presented existing research on optimizing pump operations to achieve suitable pressure and regulating storage facility water levels to transfer needed demand while lowering energy costs. When the unit price of energy is high, the amount of water supplied is reduced, and when the unit price is low, the amount of water supplied is increased. The energy consumption of water supply systems, the amount of water transferred, the organization of the energy cost structure, the use of water tanks, and other factors are investigated and analyzed to develop a system of optimized water demand management based on the use of water tanks in supplied areas to implement this scheme. This study does a numerical analysis on transferring water demand at storage facilities from peak energy cost hours to lower energy cost hours, based on the idea that energy costs may be lowered by redistributing a demand pattern.

Makaremi *et al.* (2017) presents a multi-objective optimization problem with the objective functions of energy cost and the number of pumps switched to derive an optimal pump scheduling program. When both objective functions are optimized together, a multi-objective constrained optimization problem is created. The Non-Dominated Sorting Genetic Algorithm, version II (NSGA-II) is coupled to the EPANET hydraulic simulation system to solve the problem. To handle constraints, some changes are made to the standard NSGA-II to make it self-adaptive, so that all constraints of the problem are automatically satisfied.

Makisha *et al.* (2018) conducted a more in-depth investigation of energy efficiency techniques in water supply and sanitation, as well as their application in Russian regions. Energy conservation techniques and stages of implementation are given special consideration based on the review of energy conservation methods, including a classification table and cost estimates.

Research done by Moreira *et al.* (2013) analyzed various pump characteristic curves and modeled to find the most efficient operating point to determine the best daily pumping operational scheduling pattern. In that, a genetic algorithm (GA) optimization embedded in modeling software was compared to a manual override (MO) approach. The main goal was to figure out which pumps and which daily schedules provided the most cost-effective solution. After the study, it was able to save 43.7% on daily energy costs.

Mundt *et al.* (2015) was measuring and describing the energy savings of representative Arizona water system energy efficiency projects. According to them, the results were to assist water purveyors in better understanding the energy efficiency implications of capital improvements and was to guide future project adoption. The optimization and calibration of the pressure required in water distribution systems saves significant amounts of money in annual energy costs, reduce direct water use, and provide indirect water savings in power generation as per their analysis. Utility incentive programs, such as utility-sponsored rebate programs, can play an important role in lowering the initial costs of these measures, added by Mundt *et al.* (2015).

Several algorithms have been developed to address operational priorities that are slightly different. To enable these algorithms, the control system is expected to include sensors for instantaneous irradiance, power output from PV modules, battery charge, and demand. A simple computing engine creates a priori switching schedule based on cloud cover predictions and measurements from these sensors at the installation site. To improve the system's



robustness, decisions are made with a granularity of 1 h, and this study was by Soudan *et al.* (2020).

The study done by Nebey (2021) was to design the fuzzy logic controller which was intended to manage intermittent nature of energies. However, demand and energy sources are unpredictable; hence an intelligent control system was required to manage the system appropriately using MATLAB software to design the control system. The outcome of resource combination shows that demand and supply are balanced.

By establishing the BIM system of the water supply pumping station of the Qingdao Guzhenkou water supply project, Qun *et al.* (2017) investigated the way to solve energy-saving optimization problems in the process of the whole life cycle of water supply pumping station based on BIM (Building Information System) technology and puts forward the feasible strategies of BIM application to realize the healthy and sustainable development goals.

As a result, optimization of the Hybrid Renewable Energy System (HRES) is required in a variety of domains such as system component sizing, energy management, unpredicted weather conditions, excess energy dispatch, and energy storage because these are important to reduce system cost and increase reliability. However, the mentioned results were after Rajalakshmi *et al.* (2020) reviewed recent literature on the application of optimization tools and control strategies that are particularly suited for cost minimization and reliability maximization.

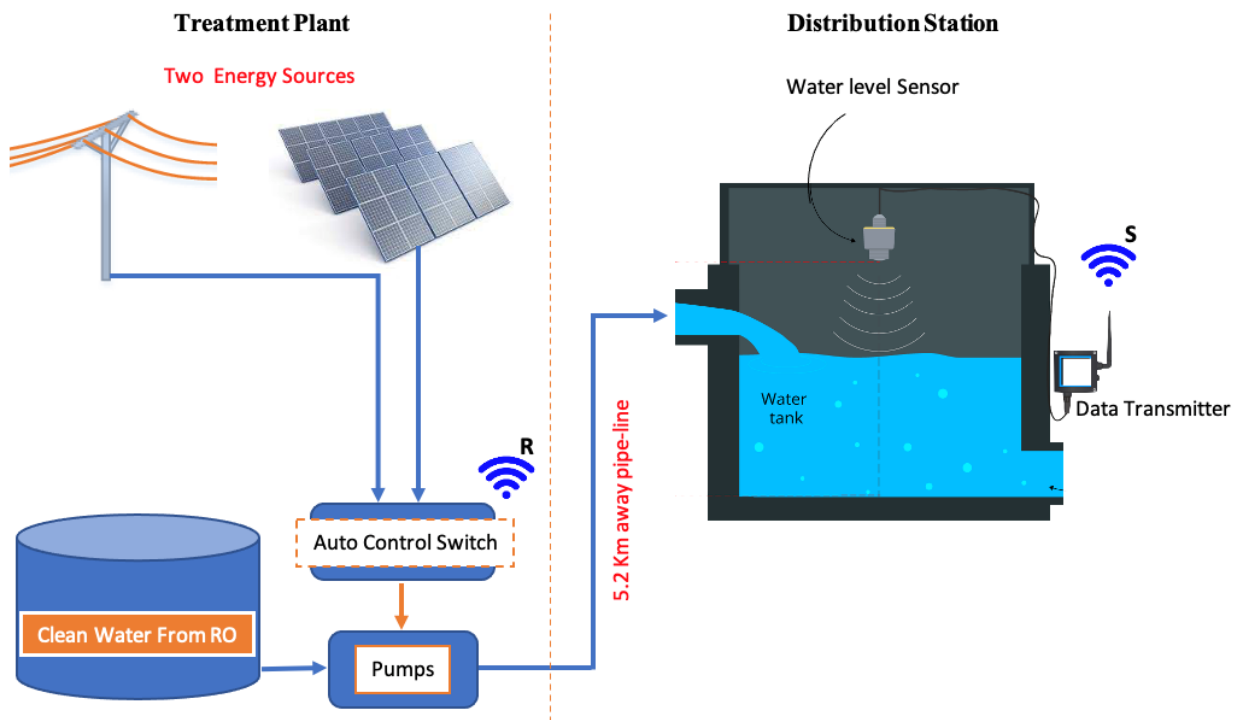
## **2.3 Overview of the System Under Consideration**

### **2.3.1 Conceptual Framework for Optimization of Ngarantoni Water Supply Scheme**

The Ngarantoni water supply network's conceptual design is shown in Fig. 1. This general framework is a large-scale overview that must be solved part-by-part in order to maximize efficiency and hence full optimization. However, as stated by the title of this project, this framework, including the supporting optimization plan (area of emphasis) as highlighted in the Figure 1, meaning, the area or part where this project focuses. The distances between the water tanks and the water sources, which, according to the original design plan; included Hazina spring water and ASA-Farm boreholes, are only indicated by a small number of measures.

### 2.3.2 Proposed System

Numerous programmed algorithms have been created, in accordance with the defined system, to handle the operational issues with the scheme's relation to energy usage. This proposed control system is anticipated to incorporate microcontrollers and sensors for water level monitoring and electrical parameter measurements such as energy, voltage, currents, etc. to perform these algorithms. The system controls the transfer (switching) of the power sources based on the water level sensed from the long-range water tank and processed using the ESP32-D0WDQ6 microprocessor from the ESP32-WROOM-32 microcontroller. The wireless master system transmits water level data from the tank, which is received by the slave system, which is where the switching process occurs.



**Figure 2: Proposed system overview**

## CHAPTER THREE

### MATERIALS AND METHODS

#### 3.1 Research Overview

The project's goal is to design and develop an intelligent system for transferring hybrid power sources to support the scheme's optimization. The system, on the other hand, contains three distinct processes. The initial step is planning, then design and development, and finally implementation. However, the document will primarily focus on the first two procedures, with the third phase occurring after approval. Besides, the methods are meant to find a means to accomplish the desired project outcome. However, to substantially enhance energy efficiency and manual power selection of the scheme's booster pumps, the system will have an Automatic Transfer Switch (ATS) feature and will be controlled electronically using data collected from a tank via a water level sensor.

##### 3.1.1 A Case Study

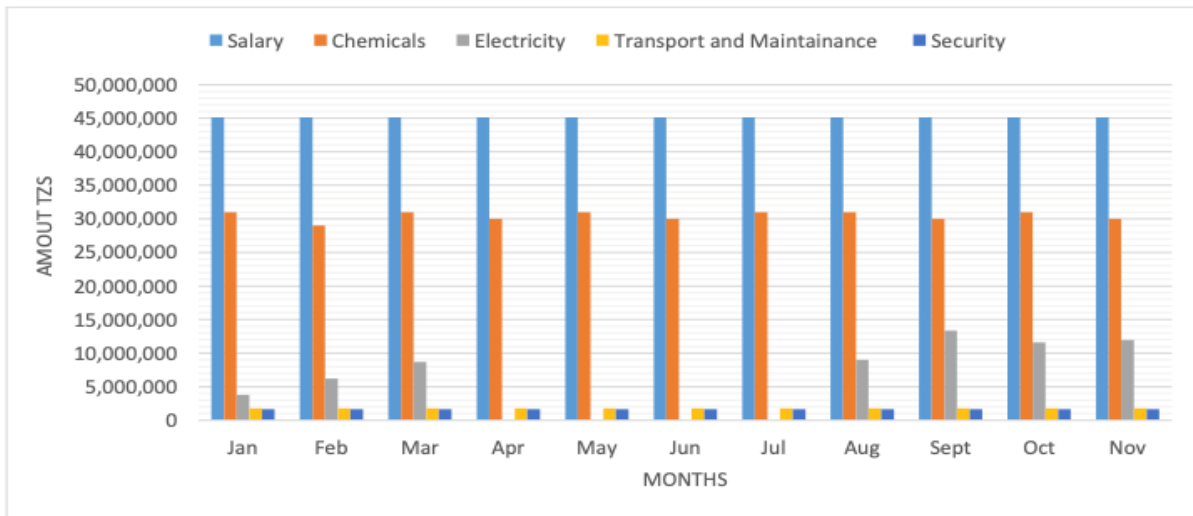
###### (i) Data Collection

There are different methods and procedures used for data collection that include survey method, documentation, questionnaire, interviews, experimentation and many more. However, they are also classified into two, Primary and secondary data collection method. Usually, every method has its strength and weakness. In order to meet the goal of this project, field observation, discussion, experimentation, interviews, and documentation are adopted for data collection. Here, the Ngarantoni Water Supply Scheme management personnel especially the engineers, technicians, operators, and other concerned individuals from other companies were interviewed and had some group discussion. Meanwhile, documentation is based on previous works. Hence this action helps to understand how the Ngarantoni Water Supply Schemes work, and the challenges incurred.

###### (ii) Primary Data Collection

As mentioned early in the data collection, field observation, interviews, documentation, and experimentation were the most used methods during the collection of data at Ngarantoni water supply scheme. However, during the observation and analysis, it was noticed that the scheme's operation was not optimal and the designed schedule of operation is not followed anymore due to

high clean water consumption rate by the consumers and the operation of the booster pumps depends on the water level of the Lemoja tank which is usually analyzed by the operator manually (by looking inside the tank) in order to alternate (change) the power sources (Solar or Grid energy) by switching on/OFF one of the sources depending on the weather condition for the solar operation or grid energy whenever the water level of the Lemoja tank is low. Grid energy is the most used source of energy at the scheme due to the low raw water production as well as high demand of clean water. Besides, the booster pumps in presence of the solar energy as the alternative source and the two borehole pumps which are connected only to the grid energy are the highest energy consumers. Furthermore, the supply of the raw water is currently done by one borehole pump since the other pump is currently down and hence the pump operation is 24 hours due to the low quantity of raw water produced to the raw water tank for Reverse Osmosis (RO) operation. Figure 3 shows the operational costs analysis.



**Figure 3: Categorization of operation costs in 2020**

- (a) The operation costs are extremely very high compared to the water revenue. Even with the small amount of revenues there seems to be no effective collection since the records show that the ratio between billed and collected revenue varies every month. From the records, the amount of money collected in all months is less than that which is billed except for February and June. There is a difference of about 16 million Tanzanian shillings between the collected and billed amount for the month of July for example.

- (b) The amount of money collected cannot cover individual costs for salary or chemicals. It can only cover electricity only. Furthermore, there are missing records of some electricity bills from April to July due to manual recording. And the data that is recorded upon assumptions has not considered the days that there was no operation going on.
- (c) Due operation challenges, especially with the membranes, it was reported that from 22<sup>nd</sup> of September to 2<sup>nd</sup> of December raw water from the boreholes was fed directly into the clean water tank and then pumped for distribution to consumers untreated. It was however surprising how there was no relief in the electricity costs even during the time of bypass.
- (d) From the data, there seem to be a higher amount of electricity bills paid compared to the energy units that are consumed at ASA-FARM. Since most operations that require the use of electricity are at ASA-FARM, the expectations were that most units will be consumed at ASA-FARM than at any other site. Surprisingly, for the months of February, March, and November more than half of the overall units were used elsewhere and the remaining at ASA-FARM site. This means there is either a fault in recordings or probably energy is lost somewhere. The summarized table for energy units is as below:

**Table 1: The overall energy units versus those that are consumed at ASA-FARM**

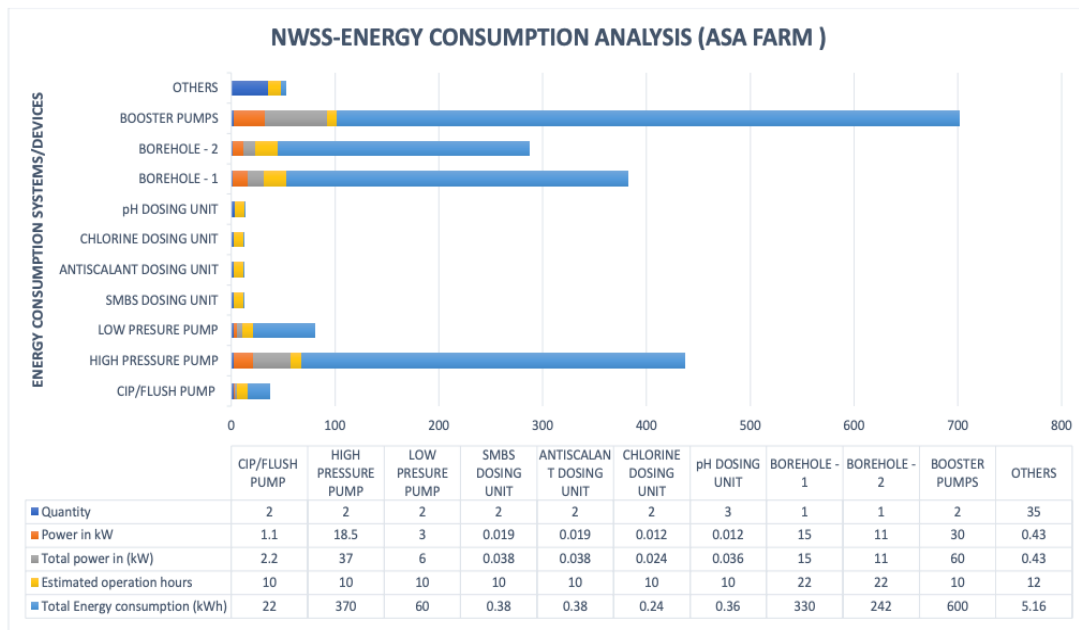
Month	Energy units overall	Energy units at ASA-Farm	Difference	% Difference
January	10792.9	-	-	-
February	17714.3	6645.9	11068.4	62.5
March	24857.1	13922.4	10934.7	44
April	-	8855.5	-	-
May	-	14692.7	-	-
June	-	17673.6	-	-
July	-	13972.3	-	-
August	25714.3	20364.6	5349.7	20.8
September	38188.3	29281.4	8906.9	23.3
October	33109.5	22202.2	10907.3	32.9
November	34191.41	16969.7	17221.71	50.4

Note that the overall energy units are upon conversion of the electricity bills to units based on 350 shillings per 1 unit of electricity (cost of units are according to the manager).

- (a) Apart from the records, the Manager’s estimations for the electricity bills were around 2 million per day without solar back up and 1.6 million per day with solar backup. However, these estimations do not correspond to the records.
- (b) The highest amount of money is used on staff salaries, followed by chemicals, electricity, transport for facilities maintenance and security respectively.
- (c) There is an issue with records of operation data and expenditure costs that has made it difficult to get accurate data. This report has therefore been prepared based on data which may have been inaccurately estimated by the operator.

**(iii) Electrical Data Analysis**

The target of this project is to cut back on the energy that booster pumps take up on the electrical grid. By maximizing the usage of water from the Hazina site (gravity flow water) and solar energy supply to supplement clean water pumping to the Lemoja tank, this is done, however, to lower electricity costs throughout the water distribution process. With added functionality such as automation of the system developed with intelligent functionalities to ease the usability of the system due to the user needs analyzed from the data collected. However, the following are the energy consumption analysis from the power grid at ASA-Farm Ngaramtoni water supply scheme.



**Figure 4: The energy consumption of electrical loads in ASA-Farm**

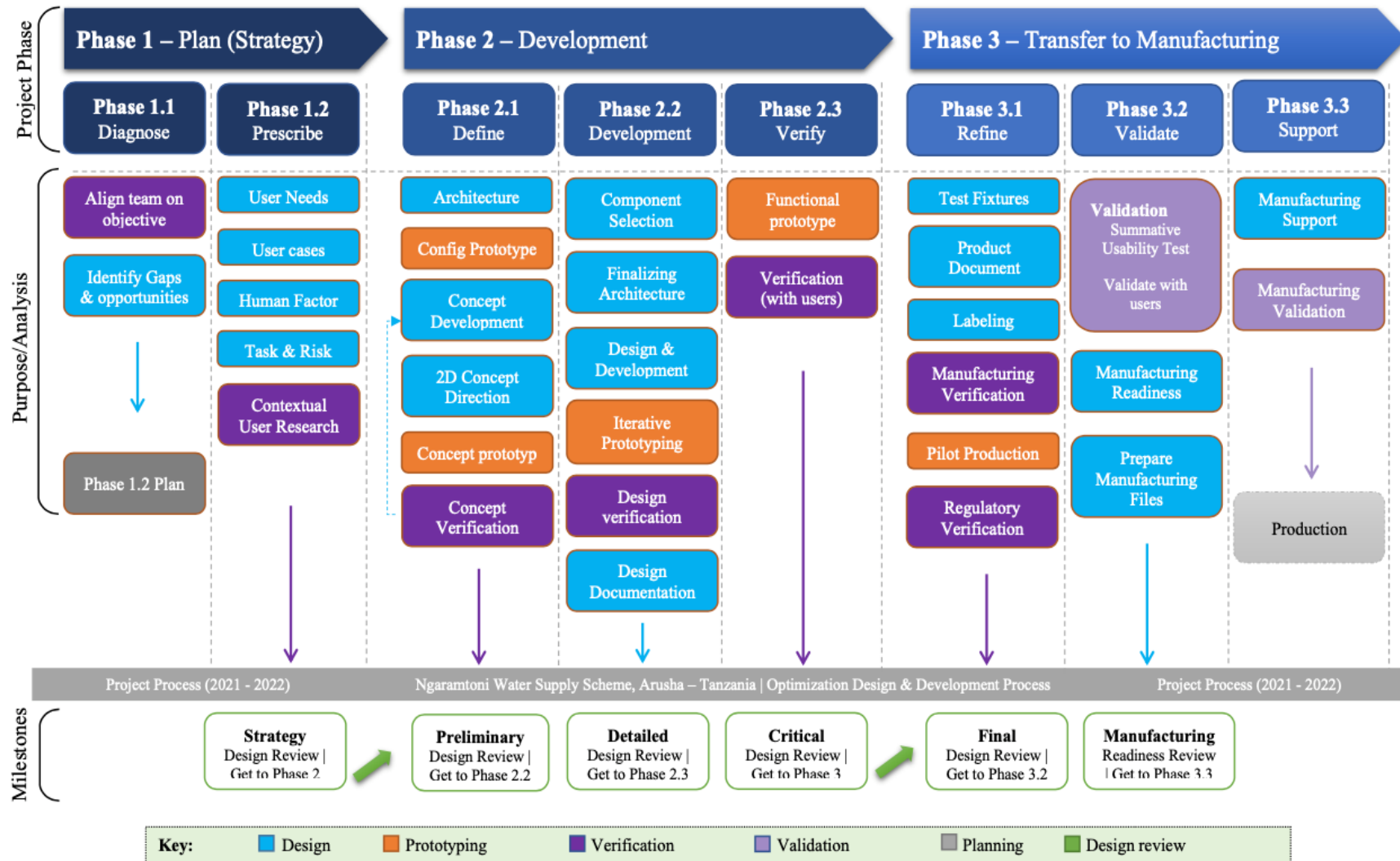
Figure 3 shows data from the electrical loads at the ASA-Farm sites of the Ngaramtoni Water Supply Scheme (NWSS). The data collected, includes the quantity or number of available electrical loads, the power consumed by each load, the total power consumed by the same loads, the estimated operation hours based on the design and current observation, and finally the total energy consumption of the loads based on their power consumption. The data is extracted from the systems' power ratings based on the manufacturer, as well as power measurements taken on-site for all electrical power and energy calculations. Therefore, as per the Fig. 3, the booster pumps consumption rate is twice high than all the other systems.

Furthermore, the total power and energy consumption of ASA-Farm site systems are as follows:

- (a) Total Power of the electrical loads in kW: **131.766 kW**.
- (b) Total Energy consumed by the electrical loads per day (12 hours) in MWh: **1.631 MWh**.
- (c) Total Energy consumed by the electrical loads per Month (30 days) in MWh: **48.93 MWh**.
- (d) Total Energy consumed by the electrical loads per year (12 months) in MWh: **587.16 MWh**.

### **3.2 Agile Method Used as The System's Process**

Figure 4 depicts a high-level perspective of the project's process. The method, on the other hand, begins with the correct identification of the project's focus areas. Second, research with theoretical reviews of the specified areas must be conducted, and hardware and software design of the needed areas. Furthermore, in order to move to the testing/verification and validation stage as an investigative approach to either conclude the project or change based on the results, an analysis of the hardware and software must be completed. The approach used for this project, however, is Agile.



**Figure 5:** Agile methodology adopted for this project



### 3.3 Research Setting

The project's experimental design, which includes both hardware and software, was developed, tested, and validated in the laboratory of The Nelson Mandela African Institution of Science and Technology (NM-AIST) at the School of Computational and Communication Science and Engineering (CoCSE) under the Center of Excellence for ICT in East Africa (CENIT@EA).

### 3.4 Software and Hardware Requirement

The procedure must be followed in order to come up with a well implemented design, as shown in Fig. 4. However, during the design phase, more was done based on field observation, literature reviews, datasheets, and certain websites as a reference for both hardware and software implementation.

#### 3.4.1 List of Software and Applications Used

**Table 2: The list of software and applications used**

Item	Description of items	Versions	Compatibility
No.	[A detailed list, Statement of Requirement/Specifications]		
1.	Arduino IDE (Mac)	1.8.13	Mac
2.	EasyEDA (Mac)	6.4.25 (6.4.25)	Mac
3.	Electric Control Techniques Simulator (EKTS)	1.0.3.0	Windows
4.	ProfiCAD (Windows)	11.2.2	Windows
5.	Microsoft Office (2019)	16.53 (21091200)	Mac
6.	Blynk App	2.27.32	Android

#### 3.4.2 List of Hardware Components

The main controlling device in this project is the ESP32-S to be programmed, contactors for power source alternation, as well as sensors to collect data for driving the system. In addition, a wireless communication (Lora Ra-01 or 02 RF module 433MHz) is a device that transmits and receives data from microcontroller, it is incorporated into the control system.

**Table 3: The list of hardware components**

<b>Item No.</b>	<b>Description of items</b>	<b>Quantity</b>	<b>Units</b>
	[A detailed list, Statement of Requirement/Specifications]		
1.	Enclosure (casing)	3	Pieces
2.	Soldering wires	1	Roll
3.	Variable Power Supply (VPS) 5 – 36V	2	Pieces
4.	Water level sensor (Ultrasonic sensor)	2	Pieces
5.	Circuit breakers of both high current	6	Pieces
6.	Switches (AC selector switches, AC Push buttons and ON/OFF switches)	3,4,2	Pieces
7.	Panel indicators, Light Emitting Diode (LED)	4,10	Pieces
8.	AC Timer relay switch	2	Pieces
9.	Terminal block connectors	10	pieces
10.	Minal block dual raw connector/cable connector wire	10	Pieces
11.	3/2-pin screw terminal block 5.08mm pitch PCB mount	10	Pieces
12.	IIC module development board TCA9548 8 Channel	4	Pieces
13.	Jumper wires male-female/male-male 2.54mm	5	Sets
14.	Breakable pin connector strip PCB	5	Pieces
15.	Single female pin header 1x40 row straight connector strip 2.54mm	5	Pieces
16.	4 Channel DC 5V/ 10A 240 AC Relay Module or Solid-State Relay	2	Pieces
17.	ESP-32-S Development Board Module	2	Pieces
18.	1.5/2.5MM single cores Pin(s) Copper Wire Cable	5,5	Meters
19.	3 phase – phase failure Relay	1	Piece
20.	HVAC distribution contactor of 32A 3-Phase	2	Pieces
21.	Solar panel, charge controller, 12v battery	1	Set
22.	LoRa Ra-01/2 433MHz module	2	Pieces
23.	20x4 LCD	2	Pieces

### **3.4.3 Description of the Major Components**

#### **(i) ESP32-WROOM-32**

The ESP32-WROOM-32 is a versatile Wireless Fidelity (Wi-Fi) plus Bluetooth and Bluetooth Low Energy (BLE) Microcontroller Unit module that is capable of handling multiple applications from low-power sensor networks to the most demanding operations like MP3 decoding, voice encoding, and music streaming. It succeeds the ESP8266, which is a low-cost Wi-Fi microcontroller with limited capabilities. The ESP32-D0WDQ6 microchip is crucial to this module and it is at the core. The integrated chip is intended to be expandable and adaptable. The clock frequency of the Central Processing Unit (CPU) can be adjusted from 80 MHz to 240 MHz, and two CPU cores can be independently regulated. The chip also includes a low-power co-processor that can be used instead of the CPU to save power while performing tasks that do not require much processing power, such as peripheral monitoring (Appendix 5).

#### **(ii) LoRa Ra-01 433MHz**

To overcome the limitations of traditional wireless designs, which do not account for distance, power consumption, and ant-interference. The Long Rang (LoRa) can be used for ultra-long-distance spread spectrum communication, as well as compatible FSK remote modulation and demodulation. Besides, it is a versatile networking device that may be used for remote irrigation systems, home building automation, automatic meter reading, and security systems. It is the appropriate answer for objects networking applications (Appendix 7).

#### **(iii) Alternative Current Contactors**

A contactor is an electrical component that is utilized in the ON and OFF switching mechanism of an electrical circuit. It is regarded as a one-of-a-kind type of relay. The primary distinction between a contactor and a relay is that the contactor is used in applications requiring a higher current carrying capacity, whereas the relay is used in situations requiring a lower current carrying capacity. These electrical devices usually have numerous contacts, compact in size and simple to install. In most cases, contactors are Normally open and provide the load with operational power when the coil is activated or energized. In most cases, they are also utilized in controlling electrical systems that include motors. Alternative Courant contactors are available in multitude of sizes and

shapes, each with their own set of features, applications, and capabilities. And they can handle a variety of direct current (DC) voltages ranging from 24 volts to thousands and amps ranging from few to thousands as well. Furthermore, these electrical devices come in a variety of sizes, ranging from small hand-held devices to those capable of measuring a meter.

#### **(iv) Three Phase Failure**

Overheating and burning of three-phase motors owing to phase failure is a typical issue in industrial operations. The "thermic-magnetic device," which is an important element of motor protection, is generally extremely slow due to both the use of a high current setting range to assure start without tripping and its electromechanical structure. As a result of being developed to eliminate the drawbacks, phase failure devices react to the following faults within 0.2 seconds (fixed) and shut down the motor.

#### **(v) Relays**

A relay is an electrical and electromechanical switches that close and open circuits. It is responsible for controlling the closing and opening of an electrical or electronic circuit contacts. The relay is not energized when the relay contact is Normally Opened (NO). However, if it is Normally Closed (NC), the relay is not activated/energized given the closed contact(s). When energy (charge or electricity) is delivered/supplied, the states are prone to changing.

### **3.5 System Design and Development**

In this sub-chapter, the following are discussed in details; conceptual framework, block diagram of the system, circuit flowchart the proposed system circuits.

#### **3.5.1 System Block Diagram**

Figure 5 shows a block diagram of a suggested system. This system is intended to aid in the optimization of the Ngaramtoni water supply scheme. The major components utilized are an ESP32 microcontroller development board as the controller, a developed automatic transfer switch (ATS) mechanism, AC and DC relays such as solid-state relay (S.S.R), AC Timers, AC Contactors, Ultrasonic sensor, Lora as a long-distance communication system, and so on. The AC

communication module PZEM-04T-V3.0 is also employed as a parameter data collector and is communicated to the Blynk IoT cloud database.

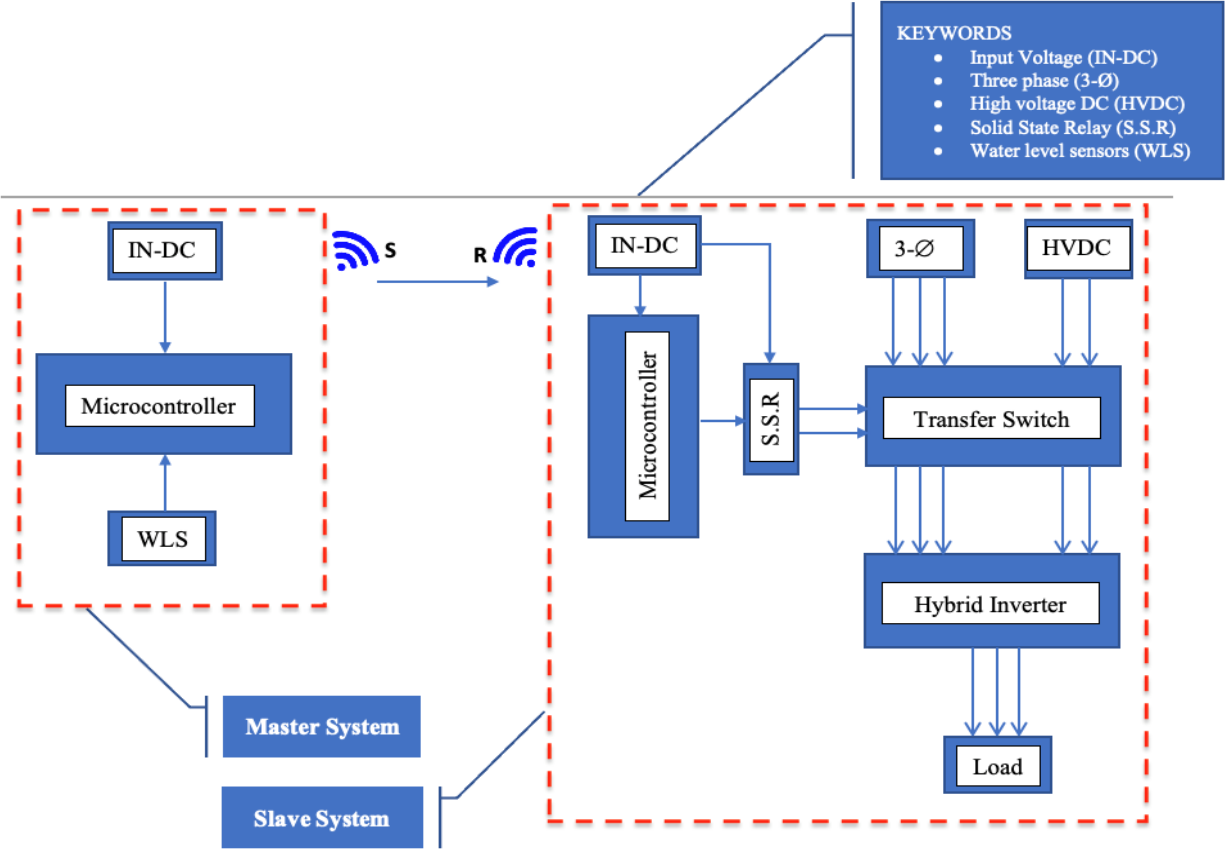
An automatic transfer switch (ATS) is a low-voltage set of components that provides a reliable way of shifting vital load connectivity linking the primary and the back-up sources. When their primary (main) power supply fails, data centers, hospitals, factories, and other facility types that require constant or near-constant uptime frequently use an emergency (alternative) power source, such as a generator or a backup utility feed.

An automatic transfer switch is a self-acting, the primary purpose of an automatic transfer switch (ATS) is to ensure that electrical power is continuously delivered from one of the power sources to a linked load circuit such as motors, computers, lights, and so on. It continuously checks electrical parameters such as voltage and frequency of primary and shifts to the power sources. The automatic transfer switch (ATS) changes (transfers) the load circuit to the other power source when the associated power source fails (unavailable). As a standard rule, most automatic transfer switches, by design, seek connection to the primary power source (utility), and only connect to the alternative power source (Solar energy, engine-generator, backup utility) when necessary; meaning, when the primary power source fails (Eaton, 2020)

The suggested system, on the other hand, employs the same automated transfer switch method with some added characteristics to become an intelligent switching. This intelligent switching is a microcontroller-based automated controller that uses gathered water level data wirelessly from a distant water tank through a long-ranged transmitter to switch the appropriate power source when the data is received by the microcontroller at the station. Besides, a device designated as a Master, controls other devices designated as slaves through communication system as shown in the block diagram. A device is a slave if it is controlled by another device, in other words, a master is a device that governs other devices or processes.

For instance, imagining a robot that can switch between two different power sources based on the water level sensed from a long-range water tank wireless using LoRa communication network to turn-on or OFF the booster-pumps and maintaining the frequent usage of solar energy rather than grid energy in order to increase efficiency of production. This proposed control system will most likely include microcontrollers such as ESP32 and sensors such as ultrasonic for water level

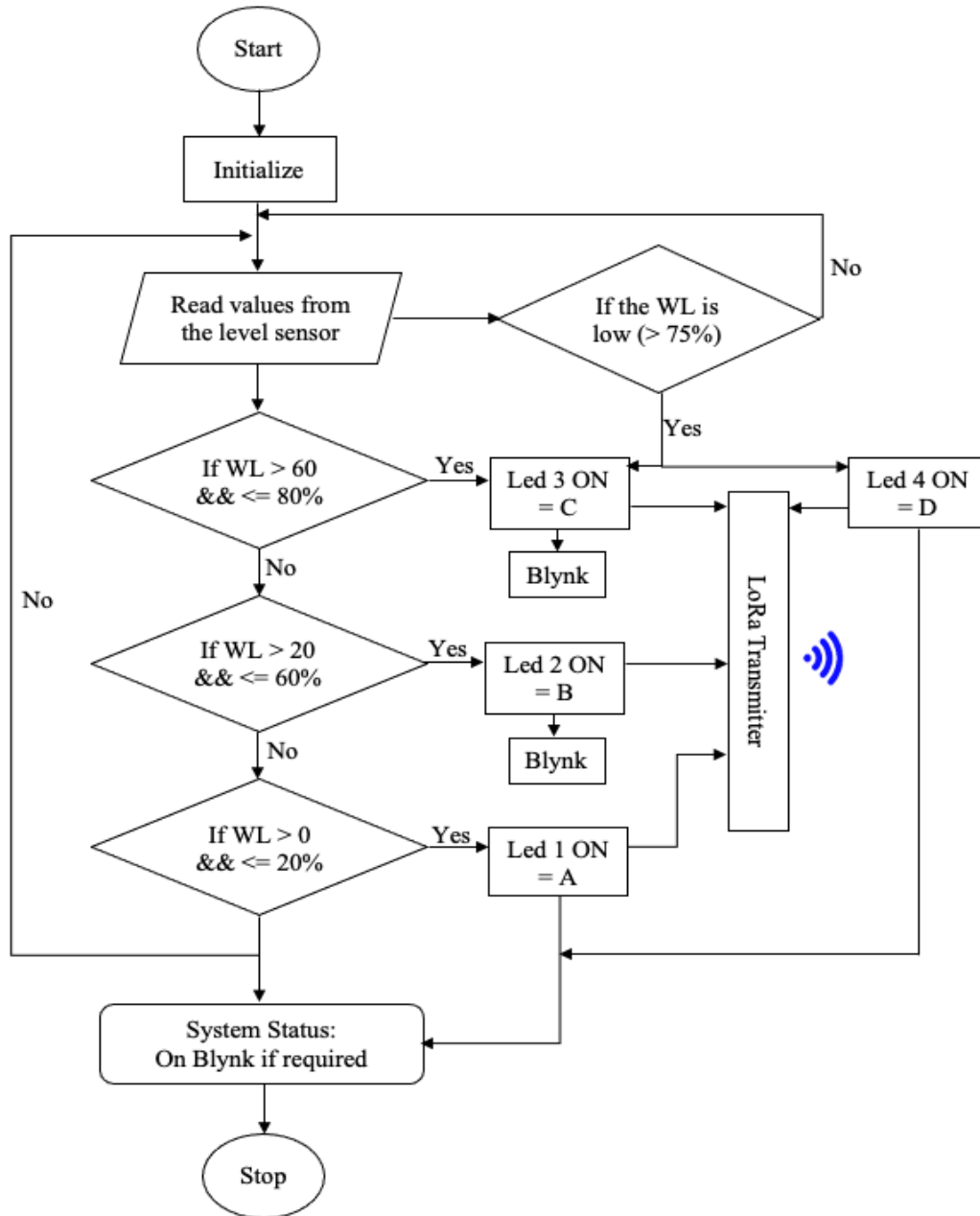
monitoring as well as AC communication module PZEM-04T-V3.0 for electrical measurements such as voltage, currents and many more.



**Figure 6: Block diagram of a proposed system to support the optimization of water supply scheme**

### 3.5.2 The Programming Flowcharts of the Proposed System

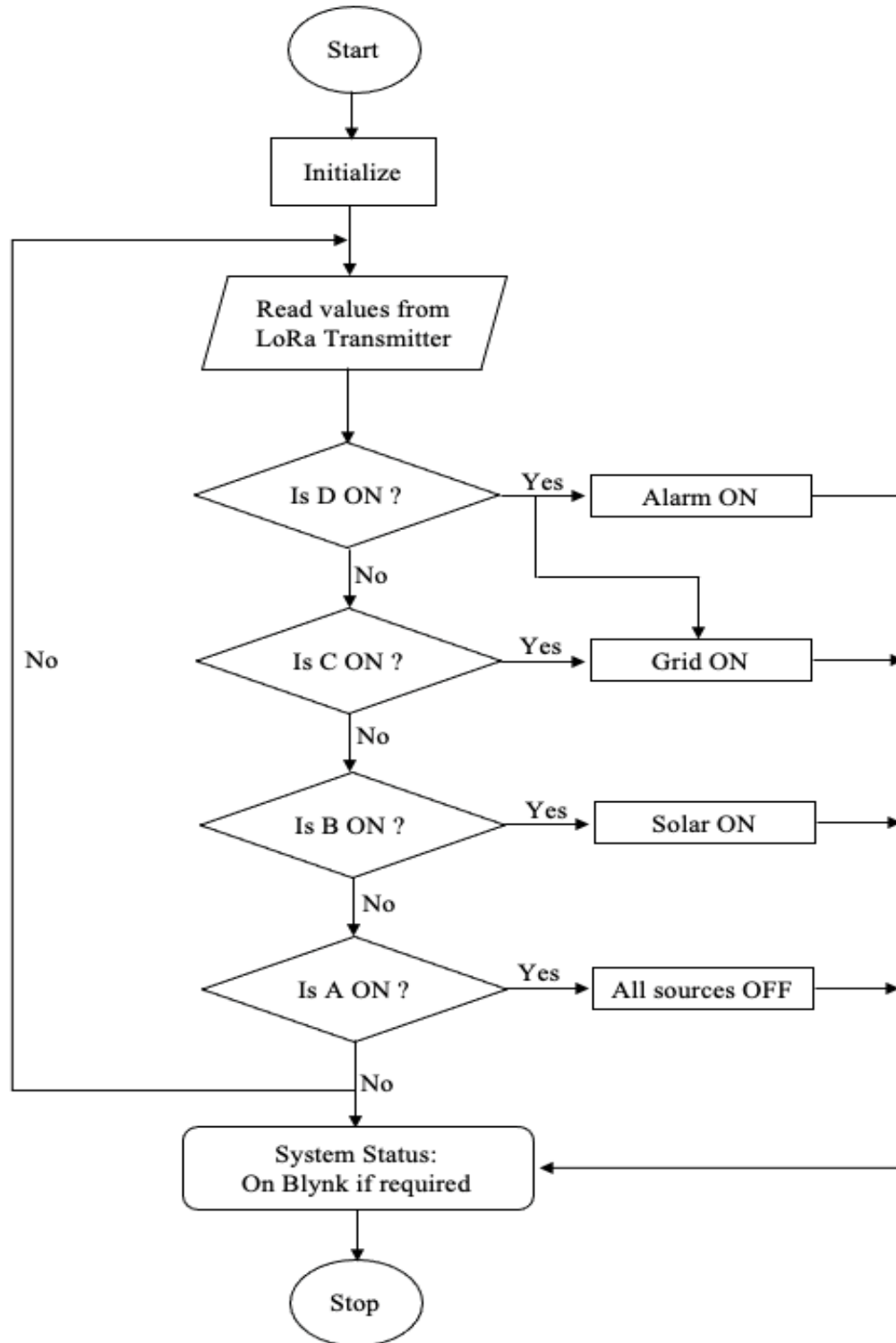
The flowcharts below describe the programming algorithm of an intelligent hybrid power transfer switch. Yet, these flowcharts reflect the master and slave systems, respectively.



**KEY:**

- Water Level = WL
- Relays = A,B,C and D

**Figure 7: Programming flowchart of a master system**



**KEY:**

- Water Level = WL
- Relays = A,B,C and D

**Figure 8: Programming flowchart of a slave system**



The programming algorithms of an electronic master system (Water level system) that detects the water level in a tank using an ultrasonic sensor module and the slave system as the receiver are shown in Figs. 7 and 8 respectively. The memory of the master system is an ESP32-WROOM-32, and it connects wirelessly with a slave electronic system via a LoRa Ra-01. This slave is constructed with an ESP32, a LoRa Ra-01, 5v relays, and other components as indicated in Table 3. The slave, however, operates the automatic transfer switch (ATS) after receiving data from the master system, which transmits the required source of energy to the pump control.

**(i) How the algorithm of the system works**

The system begins by initializing, which implies that the appropriate settings are set initially, followed by library declarations and port values. Reading the values from the ultrasonic sensor module based on the available water levels in the tank continues the procedure. Because the sensor monitors the distance of the water increment from the bottom as water is pumped into the tank by the booster pumps, the water level rise, resulting in a progressive percentage decline in the sensor reading (ultrasonic sensor).

The ultrasonic sensor will read more than 75% of the water level (WL) if the level is very low. As a result, the LED 4 on the master side turns on as the percentage increases from 75 to 90% (>75%), and the buzzer on the slave side is triggered with a delay of 300 milliseconds as the water level rises or falls within the range, but is turned OFF once the sensor reads water level less than 75%. Excessive water uses or leakage triggers the buzzer, which warns the operator.

If the water level (WL) is low, it indicates that the sensor reads more than 60 to 80% (> 60% &&= 80%). However, because the water level has reached this point, the LED 3 on the master system illuminates as the read data from the ultrasonic sensor is transmitted to the slave, and the grid energy source is activated to power the control panel of the booster pump, and the pump is turned ON immediately. Furthermore, because the range includes greater than 75%, this level remains ON whenever the buzzer is triggered as well as the LED 4.

If the water level (WL) is between 20 and 60% (>20% &&= 60 percent), the Solar energy source must turn on while the Grid energy source shuts down, and this is all done using LoRa wireless

communication. The slave system gets the data being transferred by LoRa for Automatic transfer switch (ATS) operation; therefore, the master system turns on LED 2.

If the water level (WL) is greater than 0 to 20% ( $> 0\% \&\& = 20\%$ ), it means the water tank is full, and all energy sources, including the booster pumps, must be turned OFF to isolate the control from being supplied. Furthermore, LED 1 will always be ON when the sensor detects this level and OFF when the level is not detected and the same date is transmitted to a slave system.

The Blynk algorithm is combined with the water level algorithm for more accurate water level monitoring, and this process can be monitored via Wi-Fi using the Blynk application. LEDs, on the other hand, are used for manual monitoring.

### **3.5.3 Proposed System Circuits**

Figures 9, 10, and 11 show the proposed system circuitries, which are the power circuit, control circuit, and transmitter and receiver circuits respectively. These are developed in accordance with the objectives mentioned earlier in chapter one. These circuits are created utilizing the relevant system design standards and taking all aspects into consideration. In addition, each of these circuits was simulated and tested to ensure that it served its original purpose.

(i) System's Power Circuit

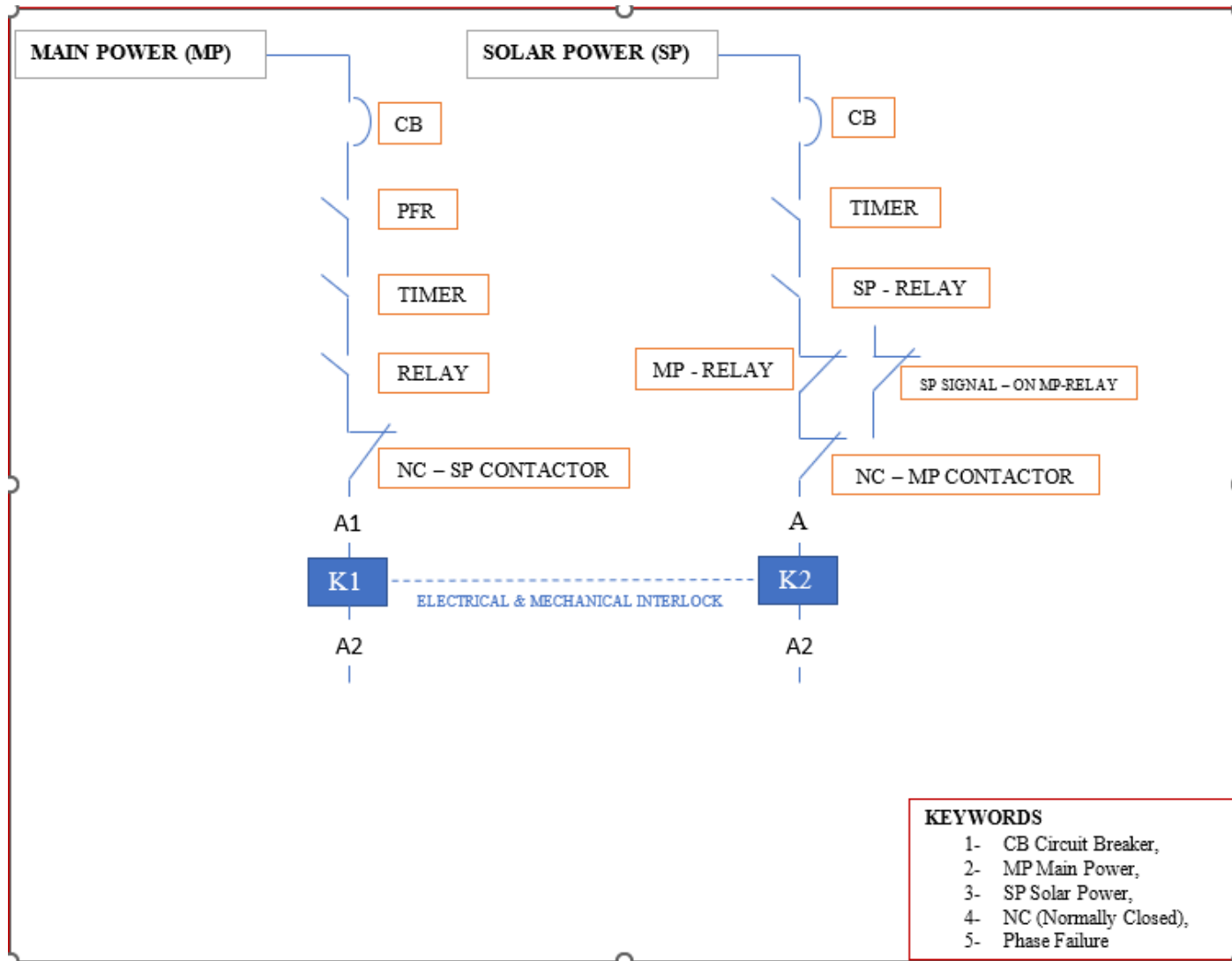


Figure 9: System's power circuit

(ii) System's Control Circuit

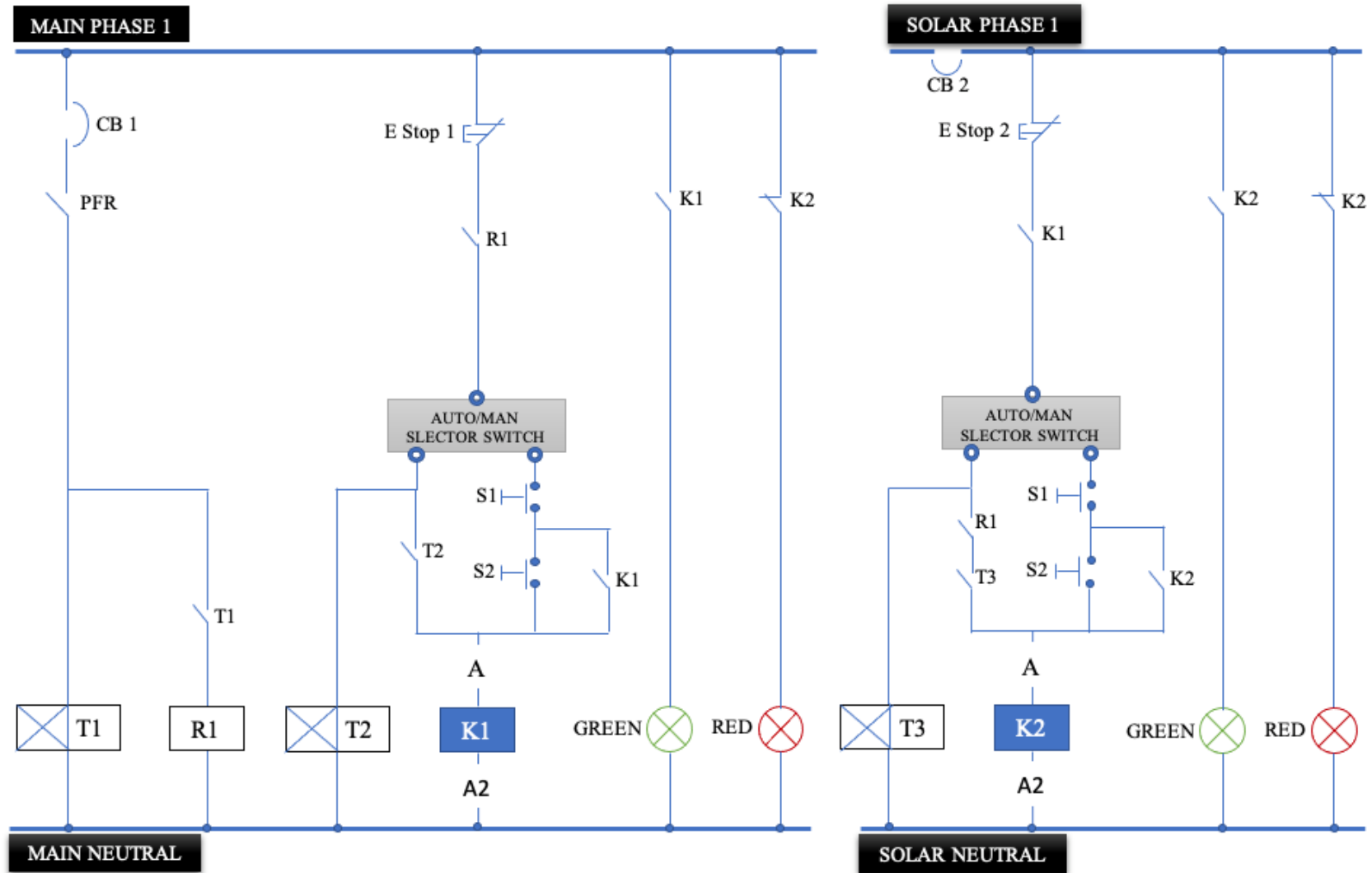


Figure 10: System's control circuit

(iii) System's General Circuit for both Transmitter and Receiver

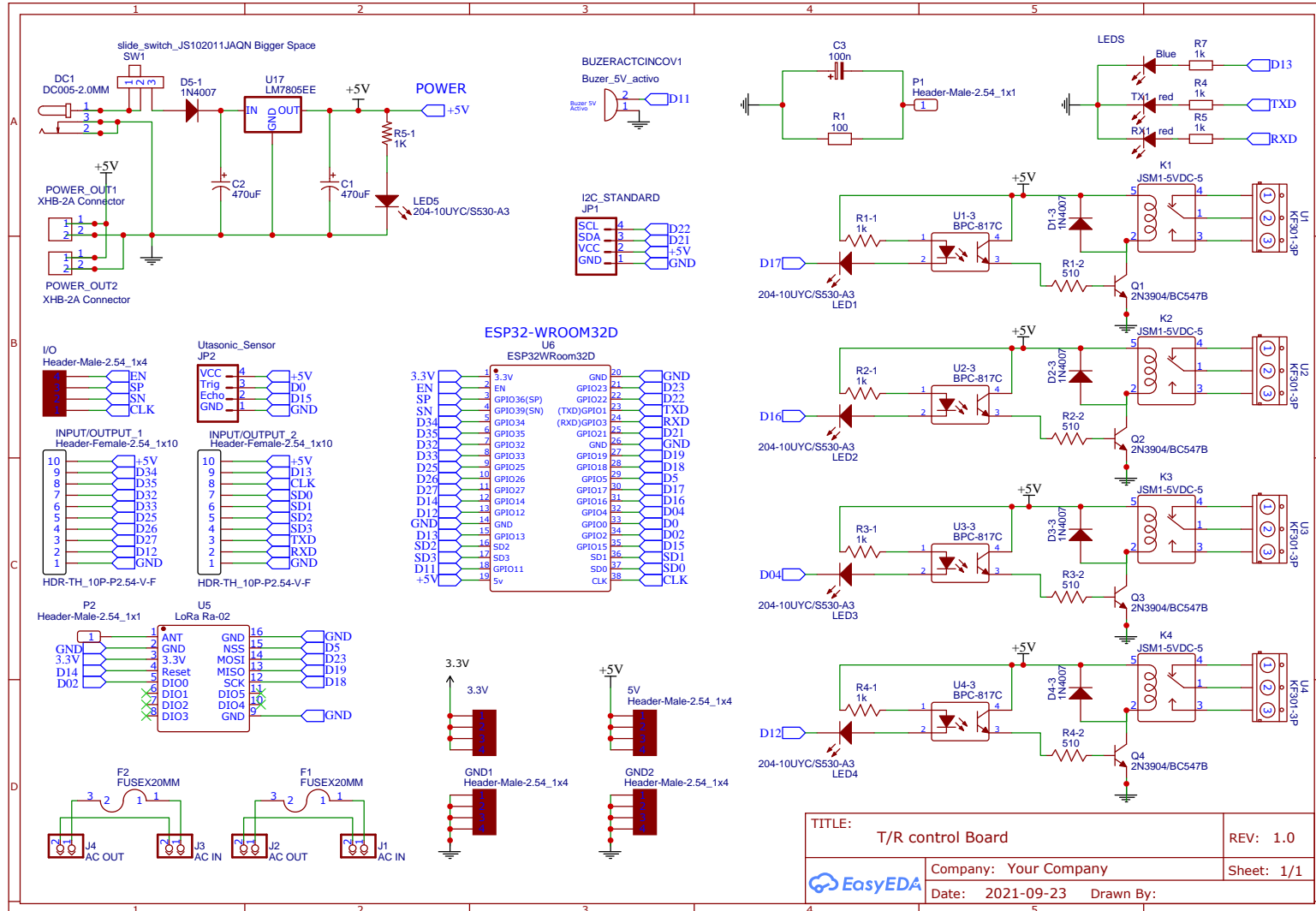


Figure 11: Master circuit for both transmitting and receiving system

## CHAPTER FOUR

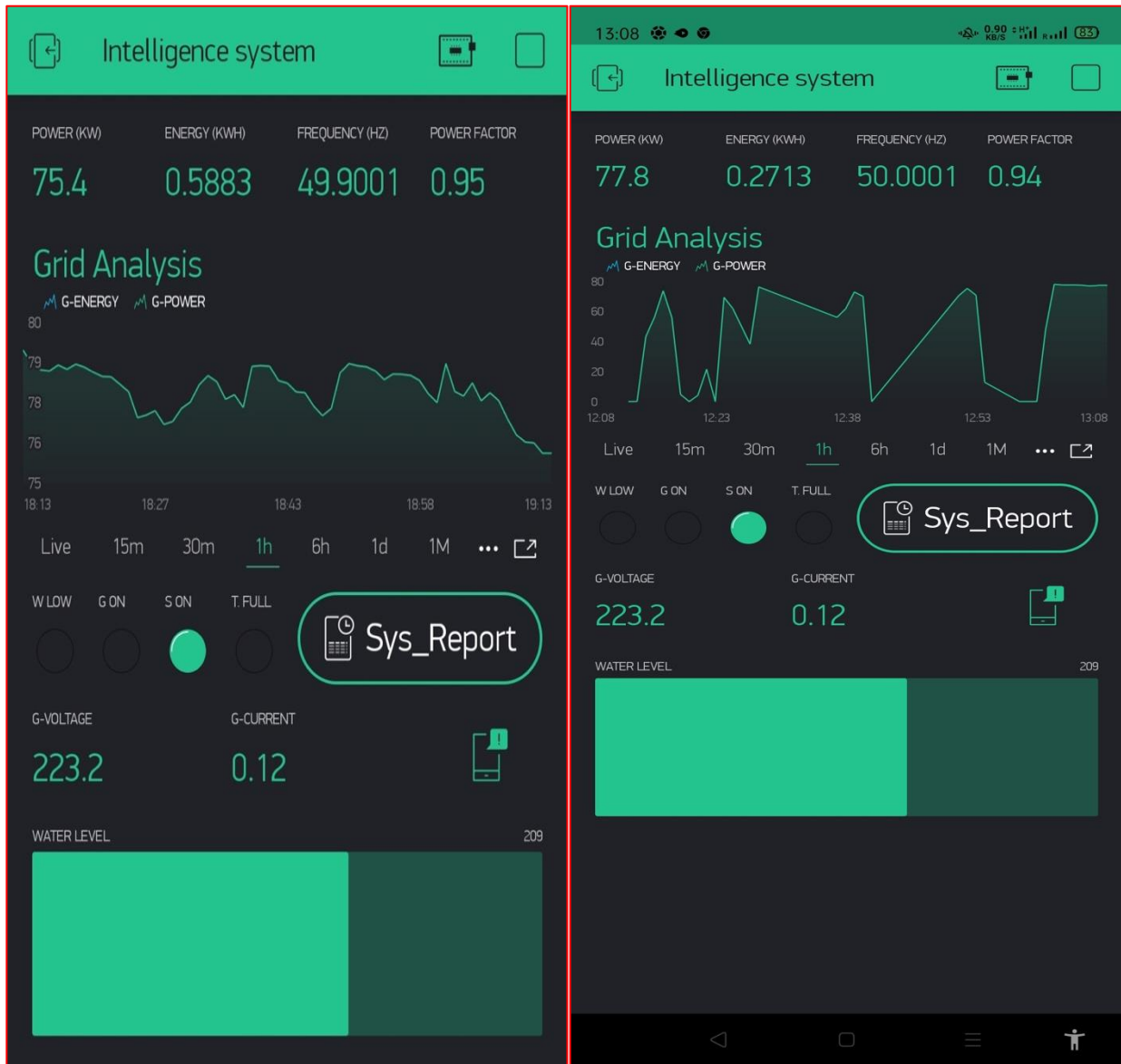
### RESULTS AND DISCUSSION

#### 4.1 Results Analysis and Representation

Data was retrieved from the system using the AC communication module PZEM-04T-V3.0 and visualized using the Blynk application and a Liquid Crystal display as shown in Fig. 12 and Appendix 2 (ii) respectively. The data collected by the sensor was processed by the ESP32-D0WDQ6 microprocessor within the ESP32-WROOM-32 microcontroller and sent to the Blynk application via the ESP32-WROOM-32 module and Wi-Fi. The data on the Figs. 13 and 14 was obtained after running up the system for several hours using the Blynk application for display, and this application has the capability of storing data and delivering it to a customized email when required.

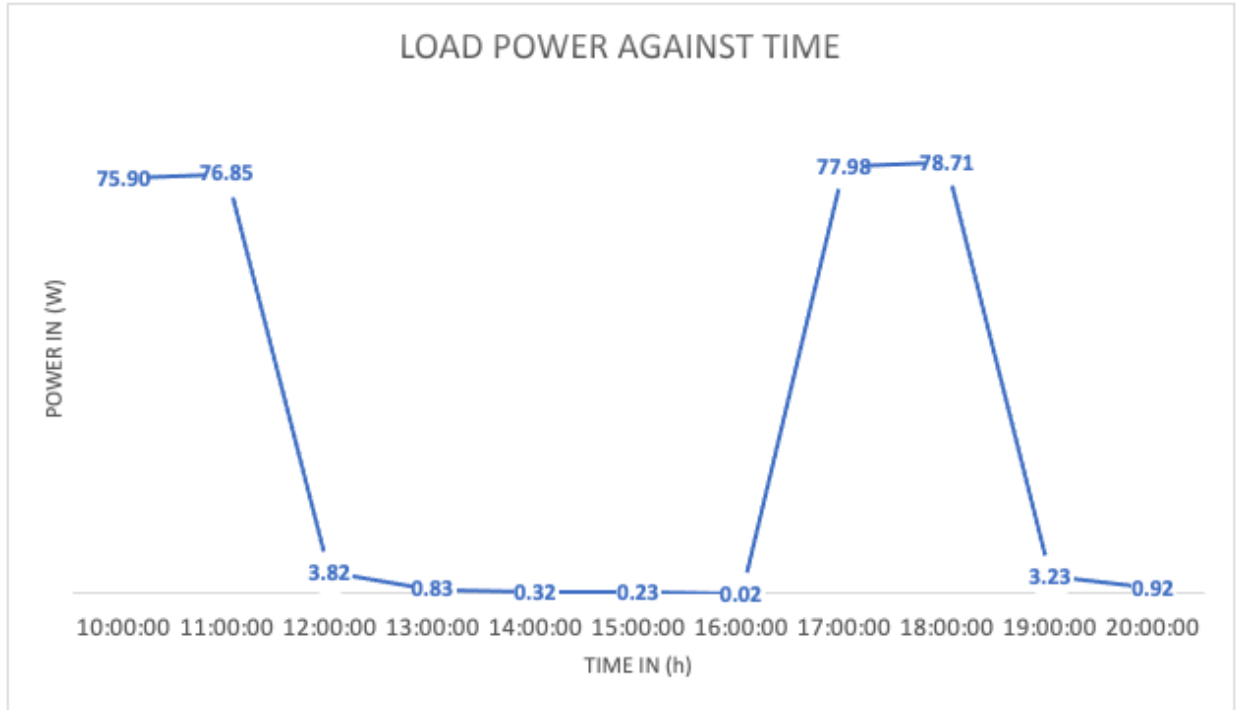
The collected data is virtualized through dashboard and structured in a graphical format using line graphs to illustrate various characteristics such as load power and energy consumption. The sensor node sends real-time data to the field, which corresponds to sensor readings. By reporting both the power of the Load present at the time of testing and the energy consumed by the Load while utilizing grid power supply, these data were utilized to show the system's functioning, as well as the capabilities of reading and storing the system's data for real-time analysis. Furthermore, instead of the actual needed size, this system is a small scale system meant for experimental analysis to ensure the desired findings to demonstrate the concept while avoiding significant expenses before the real prototype is constructed.

The electrical parameter measurements were as well shown on a (20 by 4) Liquid Crystal Display (LCD) as shown in Appendix 2 (ii). The operator may view the measurements on the LCD while they are also transferred to the cloud database for future recording or analysis through the help of internet. Appendix 2 (i) contains the electrical load power readings obtained by the designed system and presented on the LCD.



**Figure 12: Screenshots from the Blynk Application showing the system's parameter readings**

Figure 12 depicts the several electrical parameters with their SI units. As the grid source is turned ON by the system, the data is automatically recorded on the BlynkApp as shown in the figure. The representation is a real-time data on the Blynk Application with the following fields; Power (W), Energy (kWh), Frequency (Hz), Power-Factor, Voltage (V) and Current (A). However, power and energy are the only parameters represented graphically on the application for easy analysis.

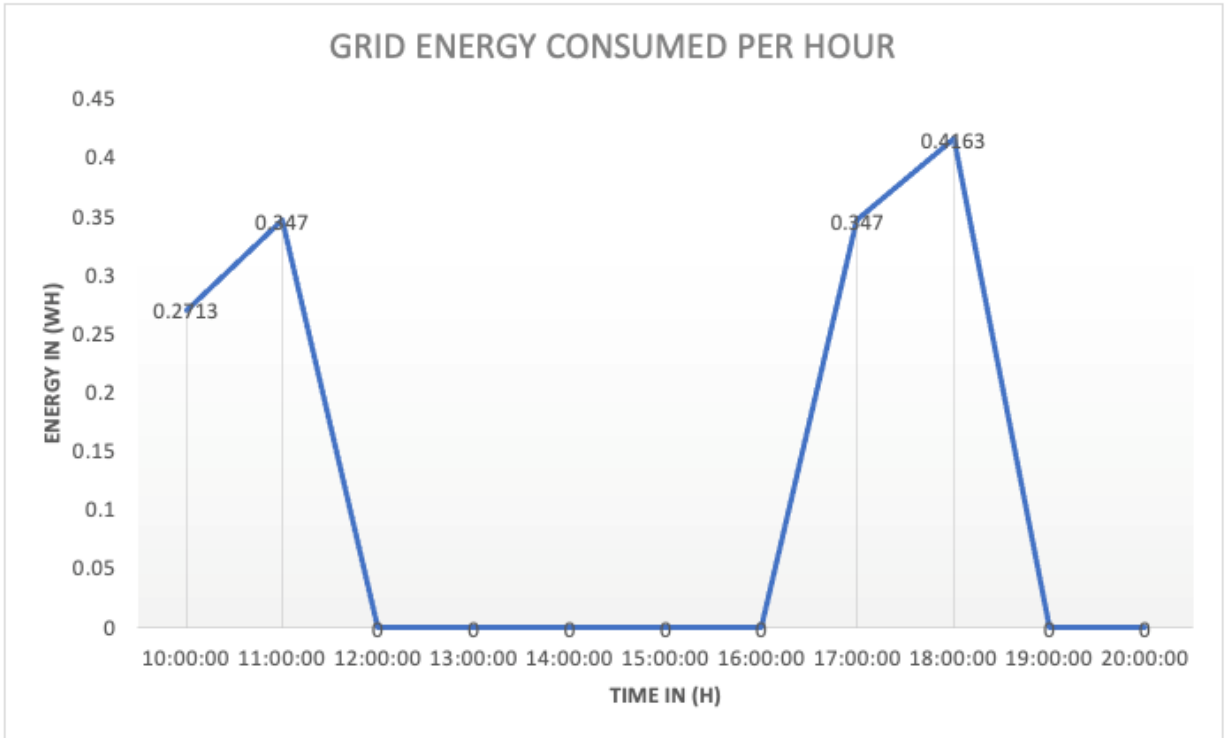


**Figure 13: The load power against time in hours**

The data on the graph are power measurements obtained from electrical loads linked to the proposed system, which represented a booster pump. Yet, the suggested system is nothing more than a switching mechanism that permits electricity to flow when turned "ON."

According to the Fig. 13, the grid was switched ON to supplying a load for an hour, meaning from 1000 h. to 1100 h, with 75.90 watts and 76.85 watts, respectively. Furthermore, the grid was turned ON again by the system at 1700 h and 1800 h, with load readings of 77.98 watts and 78.71 watts, respectively. When the grid is shut OFF, the Solar is activated depending on the water level data sensed or detected by the sensor and transmitted to the receiver. And, as the graph shows, there are no real power measurements of the load from 1200 h to 1600 h, and then again from 1900 h to 2000 h, suggesting that the Solar is ON and the grid is OFF. Since the sensor node (PZEM-04T-V3.0) linked to the load phase line of the system only gets data from the grid supply. As a result, there are no actual readings from the solar energy side.





**Figure 14: The energy consumed by the load from the grid energy source**

When comparing Figs. 13 and 14, you will observe the same switching of the energy sources, that is from Grid to Solar and back to Grid. As a result, the graph is activated anytime grid electricity is available. This diagram depicts and evaluates the proposed design's switching mechanism. That is, whenever the water level in the tank is low, meaning ranging between 60% and 80%, the grid is activated, and when the water level in the tank is average (ranging between 20% and 60%), it means solar energy is activated to maintain the water level in the tank and reduce frequent water level drops to avoid constant usage of grid supply. Furthermore, when the Grid is turned ON, the sensor resumes its data reading or recording from its previous recorded value(s), for example, 0.347 Wh at 1100 h was recorded from the graph as the data at which the grid was turned OFF, and when it was turned ON, it resumed its previous readings of 0.347 Wh at 15:00:00, as shown in the graphs.

## 4.2 Validation

Validation is the process of examining key indications to confirm that the system specifications are appropriate for the intended use. Its goal is to see if the user's specifications and requirements

have been fulfilled. Validation is thus a technique for confirming that specifications were properly written and that the system's requirements were met (Kamalrudin & Sidek, 2015). Various validation approaches were used for this developed system, including unit test, integration test, and system test. Table 4 shows a summary of the results of the tests

**Table 4: System Components Testing Results**

<b>Item No.</b>	<b>Components Requirement</b>	<b>Description</b>	<b>Score</b>
1.	Electrical components test	These components were tested and used in accordance with the specifications and functionality.	Pass
2.	Power supply indicator LEDs and the required voltages.	The supply of power is indicated. LEDs were seen when different systems were connected to the power source for operation and the appropriate voltages were measured.	Pass
3.	Power up LEDs	The power up indication LEDs were noticed when various devices were connected to the power supply and turned ON.	Pass
4.	Sensors, Ra-01 LoRa were interfaced with ESP32-WROOM-32	After programming the sensors' output, measurements were obtained on the Arduino's serial monitor, as well as the ESP32-WROOM-32's input and output ports, to ensure correct functionality and LoRa range test.	Pass
5.	7 segment voltage and current display, and LCD test	The LCD was programmed to display the required sensor readings after the 7-segment display module was connected. And the results were seen.	Pass
6.	Relays and LEDs for water levels/ power sources indicators	To guarantee that these relays and LEDs worked as expected, they were all tested and observed.	Pass

### **4.2.1 Unit Test**

Unit testing is a method of ensuring that each module of a system is fully functioning (Dyb & Dingsyr, 2008). The ESP32-WROOM-32 module, ultrasonic sensor, PZEM004Tv30 sensor module, Ra-01 LoRa modules, 5v Relays, AC contactors, and other modules were all tested for this system. Each was put through its paces in terms of powering and interacting with the ESP32-WROOM-32.

### **4.2.2 Integration Test**

This is a strategy for determining if the modules that has been tested during the unit test stage could possibly be seamlessly and accurately integrated (Nidhra, 2012). In order to achieve this, various functional modules were integrated and tested to guarantee that they functioned properly. The purpose, for example, is to "integrate and validate the water level detection system with automated switch for AC and DC hybrid power system," as mentioned in chapter one. In addition, the sensors were all properly linked to the ESP32-WROOM-32 (s) and many other electronics modules as well as electrical components and checked for any potential faults. The integration test was carried out by gradually combining components to check that they functioned correctly.

### **4.2.3 System Test**

System testing is a method of ensuring that a system runs effectively and satisfies the needs of the intended end user by putting it together as a whole and conducting tests on it. During this system testing step, the overall outcome of all modules was successfully tested. When evaluating a system, the visible functional correctness of the final product is considered rather than the structural dimension of program codes. For data storage and virtualization, some of the hardware was connected to the Blynk database in the cloud, which necessitated the usage of Wi-Fi. The system was tested after the interfacing and confirmed to work as intended.

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATION

#### 5.1 Conclusion

To reduce excess costs incurred by electricity bills, the operation of booster pumps in the Ngaramtoni water supply scheme must be optimized. The utility's existing manner of operation is exceedingly costly. By establishing an automated system for booster pump power regulation and water level measurement, this suggested system intends to address some of the operational issues by automatically controlling the system. The results reveal that if the spring source keeps the water levels over 40 percent, more solar energy is used for pumping, reducing grid energy costs because the solar energy source maintains the water levels at a sufficient proportion most of the time. Furthermore, this proposed system can operate manually and automatically without human intervention. And when the signal transmission from the tank fails, an alarm is triggered to alert the operator of loss of signal and the LED that indicates the presence of the signal turns OFF instantly. More again, when the system's source of supply fails or no power, a grid source is selected, implying that the system promptly switches to an automatic transfer switching (ATS) mode. It can, however, be operated manually based on a decision made by the operator depending on both the energy source status.

#### 5.2 Recommendations

If all water sources, particularly the spring source (gravity flow), are allowed to operate as needed without significant leakage or an increase in water consumption that exceeds the scheme's design plan, this system will function as intended. As shown in Figure 1, it is recommended to automate and wirelessly control the junction valves between the spring source and the existing tanks of Lengijave, Olkokola, and Hazina using water level detection to increase the water pressure flow to the Lemoja tank whenever the valves are closed. Furthermore, in order to improve the performance of solar panels, they should be cleaned at least once every three months. Last but not least, for general monitoring and control, this system requires a centralized web system, a very sensitive water sensor. Finally, the designed system can be used wirelessly to automate and control borehole pumps so that they turn on and OFF based on the raw water tank's water level.

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## APPENDICES

### Appendix 1: System's Codes

```

/*****
.....INTELLIGENT SYSTEM.....
Energy meter measurement using ESP32
Date Dec 2021
*****/

#include <BlynkSimpleEsp32.h>
#include <Blynk.h> // Blynk library
#include <LCD.h> // LCD library
#include <LiquidCrystal_I2C.h> // I2C library
#include <PZEM004Tv30.h> // PZEM004Tv30
library

BlynkTimer timer;

#define I2C_ADDR 0x27 // Define I2C Address for
the PCF8574T

//...The following are the I2C (PCF8574) pin
assignments to LCD connections...//

#define BACKLIGHT_PIN 3

#define En_pin 2
#define Rw_pin 1
#define Rs_pin 0
#define D4_pin 4
#define D5_pin 5
#define D6_pin 6
#define D7_pin 7

#define LED_OFF 1
#define LED_ON 0

#define BLYNK_PRINT Serial

LiquidCrystal_I2C lcd(I2C_ADDR, En_pin,
Rw_pin, Rs_pin, D4_pin, D5_pin, D6_pin, D7_pin);

//Auth Token in the Blynk App received via email-//

char auth[] = "..."; //--- Auth Token ---//

//....WiFi credentials and password here.....//

char ssid[] = "..."; //<---SSID name

lcd.setBacklightPin(BACKLIGHT_PIN,
POSITIVE);
lcd.setBacklight(LED_ON);
lcd.backlight(); //Activate backlight
}

void loop() {

Serial.print("Custom Address:");
Serial.println(pzem.readAddress(1), HEX);
Serial.println(pzem1.readAddress(0), HEX);

//-----Read the data from the sensor-----//

float power = pzem.Power();
float energy = pzem.Energy();
float frequency = pzem.Frequency();
float pf = (pzem.Pf()) ;

float power1 = pzem1.Power();
float energy1 = pzem1.Energy();
float frequency1 = pzem1.Frequency();
float pf1 = pzem1.Pf();

//-----Check if the data is valid-----//

if (isnan(Power)) {
Serial.println("Error reading power");
} else if (isnan(Energy)) {
Serial.println("Error reading energy");
} else if (isnan(Frequency)) {
Serial.println("Error reading frequency");
} else if (isnan(Pf)) {
Serial.println("Error reading power factor");
} else {

// -----Print the values to the Serial console-----//

```



```

char pass[] = "..."; //<---Password

{
int pinValue = param.asInt(); // assigning incoming
value from pin v1 to a variable
if (pinValue == 1){
pzem.resetEnergy();
Serial.println("Reset");
}

// process received value
}

//.....//

if defined(ESP32)
PZEM004Tv30 pzem(Serial2, 17, 16);
PZEM004Tv30 pzem1(Serial2, 17, 16);
else
PZEM004Tv30 pzem(Serial2);
PZEM004Tv30 pzem1(Serial2);
endif

void setup() {
Serial.begin(115200);

//pzem.resetEnergy()
Blynk.begin(auth, ssid, pass); // Server

lcd.begin(20,4);

Serial.print("power: ");    Serial.print(power);
Serial.println("W");
Serial.print("energy: ");    Serial.print(energy,3);
Serial.println("Wh");
Serial.print("frequency: "); Serial.print(frequency,
1); Serial.println("Hz");
Serial.print("pf: ");        Serial.println(pf);

    {
lcd.setCursor(0,0);    lcd.print("Power: ");
lcd.print(power);      lcd.println("W   ");
lcd.setCursor(0,1);    lcd.print("Energy: ");
lcd.print(energy,3);    lcd.println("Wh   ");
lcd.setCursor(0,2);    lcd.print("Frequency: ");
lcd.print(frequency, 1); lcd.println("Hz   ");
lcd.setCursor(0,3);    lcd.print("Power_Factor:
");    lcd.print(pf);
    }

// -----For Grid System----- //

Blynk.virtualWrite(v3,Power);
Blynk.virtualWrite(v4,Energy,3);
Blynk.virtualWrite(v5,Frequency, 1);
Blynk.virtualWrite(v6,Pf);

}
Serial.println();
delay(3000);

{
Blynk.run();
}

```

```

/*****
.....Transmitter Lora Module.....
Water level indicator and control using ESP32 and Ultrasonic sensor
Date Dec 2021
*****/

```

```

#include <LoRa.h> // Lora library
#include <SPI.h> // SPI library
#include <Newping.h> // ping library

#define led4 25 // 0% Buzzer On
#define led3 26 // 25% Grid ON and Solar OFF
#define led2 27 // 50% Grid OFF and Solar ON
#define led1 13 // 100% Power source OFF

#define echopin 4 // echo pin
#define trigpin 0 // Trigger pin

#define ss 5
#define rst 14
#define dio0 2

Newping sonar(trigpin, echopin, 90); // Newping
setup of pins and maximum distance.

int maximumRange 90 // Maximum height of tank in
cm
long duration;
float v; // The volume measurement in cubic
cm
float distance; // The height of water level
measured in cm
int r = 43.2; // Radius of tank in cm
//int cap; Capacity in liters
int actual_height; // Actual height in cm

void setup() {
  Serial.begin (115200);

  {
    pinMode(trigpin, OUTPUT);
    pinMode(echopin, INPUT);

    pinMode(led1, OUTPUT); // Tank full/
    pinMode(led2, OUTPUT); // Solar On
  }
  {
    delay(50);
    Serial.print("Distance is: ");
    Serial.print(sonar.ping_cm());
    Serial.println(" cm");
    LoRa.beginPacket(); ///send packet
    LoRa.print(sonar.Ping_cm());
    LoRa.endPacket();
    delay(200);
  }
  {
    //long duration, distance;
    digitalWrite(trigpin, LOW);
    delayMicroseconds(10);

    digitalWrite(trigpin, HIGH);
    delayMicroseconds(20);

    digitalWrite(trigpin, LOW);
    duration = pulseIn(echopin, HIGH);
    distance= duration/48.2;
    delay (60);
    actual_height = maximumRange - distance;
    v = ((3.14*(r*r))*(actual_height));
    cap = v/1000; // final capacity in liters
    delay(300);
  }
  if (distance > 75) // Buzzer action
  {
    digitalWrite(led4,HIGH);
    delay(300); //BUZZER BEEPING
    digitalWrite(led4,LOW);
    delay(300);
  }
  else
  {
    digitalWrite(led4,LOW); //BUZZER OFF
  }
}

```

```

pinMode(led3, OUTPUT); // Grid On
pinMode(led4, OUTPUT); // Buzzer connected

digitalWrite(led1, LOW);
digitalWrite(led2, LOW);
digitalWrite(led3, LOW);
digitalWrite(led4, LOW);

delay(1000);
}

{
  while (!Serial);

  Serial.println("LoRa Receiver");
  LoRa.setPins(ss, rst, dio0);

  {
    Serial.println("Starting LoRa failed!");
    while (1);

    LoRa.setTxPower(20);
  }
  LoRa.setSpreadingFactor(10);
  //LoRa.setSignalBandwidth(62.5E3);
  //LoRa.crc();

  if( (distance > 60) && (distance <= 80) )
  {
    digitalWrite(led3,HIGH);
  }
  else
  {
    digitalWrite(led3,LOW);
  }

  if( (distance > 20) && (distance <= 60) )
  {
    digitalWrite(led2,HIGH);
  }
  else
  {
    digitalWrite(led2,LOW);
  }

  if( (distance > 0) && (distance <= 20) )
  {
    digitalWrite(led1,HIGH);
  }
  else
  {
    digitalWrite(led1,LOW);
  }
}

```

```

/*****
.....Receiver Lora Module.....
Water level indicator and control using ESP32 and Ultrasonic sensor
Date Dec 2021
*****/

```

```

#include<LoRa.h> // Lora library
#include <SPI.h> // SPI library

#define ss 5
#define rst 14
#define dio0 2

#define RelayPin4 32 // 0% Buzzer ON
#define RelayPin3 33 // 25% Grid ON
#define RelayPin2 27 // 50% Grid OFF
#define RelayPin1 13 // 100% All source OFF

void setup() {
  { Serial.begin(115200);

  pinMode(RelayPin1, OUTPUT); // Tank full
  pinMode(RelayPin2, OUTPUT); // Solar On
  pinMode(RelayPin3, OUTPUT); // Grid On
  pinMode(RelayPin4, OUTPUT); // Buzzer

  digitalWrite(RelayPin1, LOW);
  digitalWrite(RelayPin2, LOW);
  digitalWrite(RelayPin3, LOW);
  digitalWrite(RelayPin4, LOW);

  delay(1000);

  while (!Serial);
  Serial.println("LoRa Receiver");
  LoRa.setPins(ss, rst, dio0);
  { Serial.println("Starting LoRa failed!");
    while (1); }
  LoRa.setSpreadingFactor(10);
  LoRa.setSignalBandwidth(62.5E3);
  LoRa.crc();
}
}

void loop() {
  // --- try to parse packet --- //

  int packetSize = LoRa.parsePacket();
  if (packetSize)
  {
    // --- received a packet --- //
    Serial.print("distance is ");

    // --- read packet --- //
    while (LoRa.available()) {
      Serial.print((char)LoRa.read()); }

    targetDistance = LoRa.parseInt();
    Serial.print(targetDistance);
    Serial.print(" cm ");
    Serial.println(" ");

    { if (targetDistance > 75 {
      digitalWrite(RelayPin4,HIGH);
      delay(300); // BUZZER BEEPING
      digitalWrite(RelayPin4,LOW);
      delay(300); }
      else
      { digitalWrite(RelayPin4,LOW); }

    if( (targetDistance > 60) && (targetDistance <= 80) )
      { digitalWrite(RelayPin3,HIGH)}
      else
      { digitalWrite(RelayPin3,LOW); }

    if( (targetDistance > 20) && (targetDistance <= 60) )
      { digitalWrite(RelayPin2,HIGH); }
      else
      { digitalWrite(RelayPin2,LOW); }

    if( (targetDistance > 0) && (targetDistance <= 20)
      { digitalWrite(RelayPin1,HIGH); }
      else
      { digitalWrite(RelayPin1,LOW); } } } }

```

## Appendix 2: Data Monitoring Devices, Application and Retrieved Data

### (i) Blynk application and retrieved data



2022-01-05 12:00:00	40.57313019390580
2022-01-05 13:00:00	75.89914772727270
2022-01-05 14:00:00	76.85284090909090
2022-01-05 15:00:00	3.8209276018101000
2022-01-05 16:00:00	0.8320075757575610
2022-01-05 17:00:00	74.98191287878790
2022-01-05 18:00:00	78.26530805687210
2022-01-05 19:00:00	77.58712121212130
2022-01-05 20:00:00	77.98199052132710
2022-01-05 21:00:00	78.70938864628810

### (ii) LCD Display



## Appendix 3: System Designing and Assembling

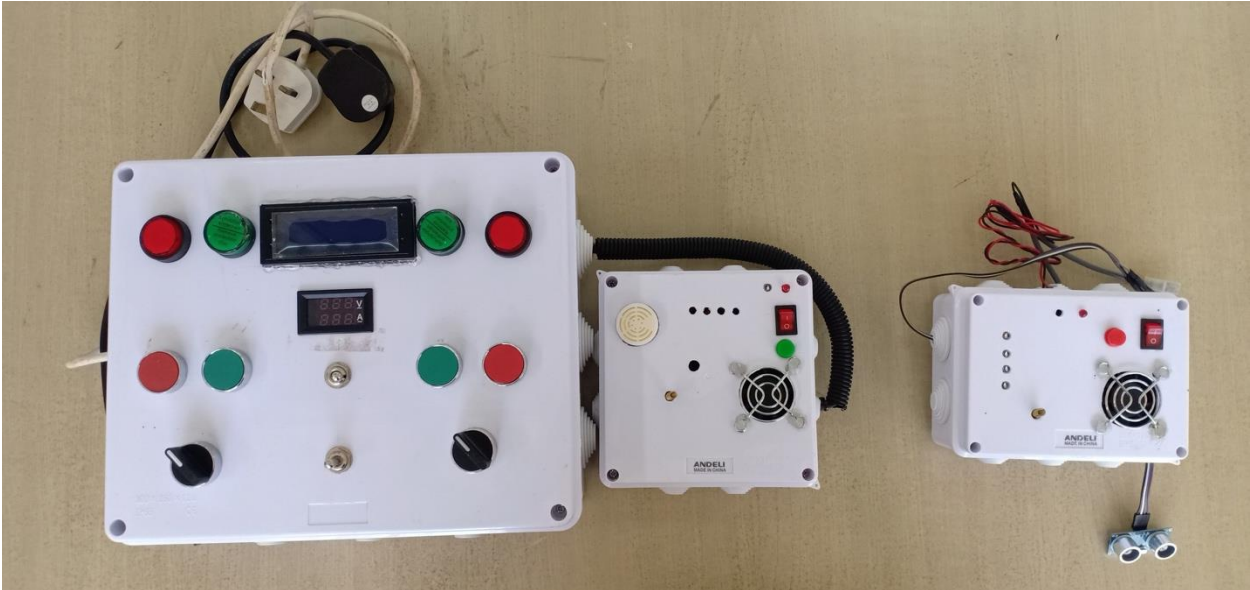
### (i) Designing and Assembling



### (ii) System testing site



Appendix 4: Final System



## Appendix 5: ESP32-WROOM-32 Specification and pin details

### (i) Specification

Categories	Items	Specifications
Certification	RF certification	FCC/CE-RED/IC/TELEC/KCC/SRRC/NCC
	Wi-Fi certification	Wi-Fi Alliance
	Bluetooth certification	BQB
	Green certification	RoHS/REACH
Test	Reliability	HTOL/HTSL/uHAST/TCT/ESD
Wi-Fi	Protocols	802.11 b/g/n (802.11n up to 150 Mbps) A-MPDU and A-MSDU aggregation and 0.4 $\mu$ s guard interval support
	Frequency range	2.4 GHz ~ 2.5 GHz
Bluetooth	Protocols	Bluetooth v4.2 BR/EDR and BLE specification
	Radio	NZIF receiver with -97 dBm sensitivity
		Class-1, class-2 and class-3 transmitter
		AFH
Audio	CVSD and SBC	

Categories	Items	Specifications
Hardware	Module interfaces	SD card, UART, SPI, SDIO, I <sup>2</sup> C, LED PWM, Motor PWM, I <sup>2</sup> S, IR, pulse counter, GPIO, capacitive touch sensor, ADC, DAC, Two-Wire Automotive Interface (TWA <sup>®</sup> ), compatible with ISO11898-1 (CAN Specification 2.0)
	On-chip sensor	Hall sensor
	Integrated crystal	40 MHz crystal
	Integrated SPI flash	4 MB
	Operating voltage/Power supply	3.0 V ~ 3.6 V
	Operating current	Average: 80 mA
	Minimum current delivered by power supply	500 mA
	Recommended operating temperature range	-40 °C ~ +85 °C
	Package size	(18.00±0.10) mm × (25.50±0.10) mm × (3.10±0.10) mm
	Moisture sensitivity level (MSL)	Level 3

### (ii) Pin numbers descriptions

Name	No.	Type	Function
GND	1	P	Ground
3V3	2	P	Power supply
EN	3	I	Module-enable signal. Active high.
SENSOR_VP	4	I	GPIO36, ADC1_CH0, RTC_GPIO0
SENSOR_VN	5	I	GPIO39, ADC1_CH3, RTC_GPIO3
IO34	6	I	GPIO34, ADC1_CH6, RTC_GPIO4
IO35	7	I	GPIO35, ADC1_CH7, RTC_GPIO5
IO32	8	I/O	GPIO32, XTAL_32K_P (32.768 kHz crystal oscillator input), ADC1_CH4, TOUCH9, RTC_GPIO9
IO33	9	I/O	GPIO33, XTAL_32K_N (32.768 kHz crystal oscillator output), ADC1_CH5, TOUCH8, RTC_GPIO8



Name	No.	Type	Function
IO25	10	I/O	GPIO25, DAC_1, ADC2_CH8, RTC_GPIO6, EMAC_RXD0
IO26	11	I/O	GPIO26, DAC_2, ADC2_CH9, RTC_GPIO7, EMAC_RXD1
IO27	12	I/O	GPIO27, ADC2_CH7, TOUCH7, RTC_GPIO17, EMAC_RX_DV
IO14	13	I/O	GPIO14, ADC2_CH6, TOUCH6, RTC_GPIO16, MTMS, HSPICLK, HS2_CLK, SD_CLK, EMAC_TXD2
IO12	14	I/O	GPIO12, ADC2_CH5, TOUCH5, RTC_GPIO15, MTDI, HSPIQ, HS2_DATA2, SD_DATA2, EMAC_TXD3
GND	15	P	Ground
IO13	16	I/O	GPIO13, ADC2_CH4, TOUCH4, RTC_GPIO14, MTCK, HSPID, HS2_DATA3, SD_DATA3, EMAC_RX_ER
SHD/SD2*	17	I/O	GPIO9, SD_DATA2, SPIHD, HS1_DATA2, U1RXD
SWP/SD3*	18	I/O	GPIO10, SD_DATA3, SPIWP, HS1_DATA3, U1TXD
SCS/CMD*	19	I/O	GPIO11, SD_CMD, SPICS0, HS1_CMD, U1RTS
SCK/CLK*	20	I/O	GPIO6, SD_CLK, SPICLK, HS1_CLK, U1CTS
SDO/SD0*	21	I/O	GPIO7, SD_DATA0, SPIQ, HS1_DATA0, U2RTS
SDI/SD1*	22	I/O	GPIO8, SD_DATA1, SPID, HS1_DATA1, U2CTS
IO15	23	I/O	GPIO15, ADC2_CH3, TOUCH3, MTDO, HSPICS0, RTC_GPIO13, HS2_CMD, SD_CMD, EMAC_RXD3
IO2	24	I/O	GPIO2, ADC2_CH2, TOUCH2, RTC_GPIO12, HSPWP, HS2_DATA0, SD_DATA0
IO0	25	I/O	GPIO0, ADC2_CH1, TOUCH1, RTC_GPIO11, CLK_OUT1, EMAC_TX_CLK
IO4	26	I/O	GPIO4, ADC2_CH0, TOUCH0, RTC_GPIO10, HSPHD, HS2_DATA1, SD_DATA1, EMAC_TX_ER
IO16	27	I/O	GPIO16, HS1_DATA4, U2RXD, EMAC_CLK_OUT
IO17	28	I/O	GPIO17, HS1_DATA5, U2TXD, EMAC_CLK_OUT_180
IO5	29	I/O	GPIO5, VSPICS0, HS1_DATA6, EMAC_RX_CLK
IO18	30	I/O	GPIO18, VSPICLK, HS1_DATA7
IO19	31	I/O	GPIO19, VSPIQ, U0CTS, EMAC_TXD0
NC	32	-	-
IO21	33	I/O	GPIO21, VSPIHD, EMAC_TX_EN
RXD0	34	I/O	GPIO3, U0RXD, CLK_OUT2
TXD0	35	I/O	GPIO1, U0TXD, CLK_OUT3, EMAC_RXD2
IO22	36	I/O	GPIO22, VSPWP, U0RTS, EMAC_TXD1
IO23	37	I/O	GPIO23, VSPID, HS1_STROBE
GND	38	P	Ground

**Notice:**

\* Pins SCK/CLK, SDO/SD0, SDI/SD1, SHD/SD2, SWP/SD3 and SCS/CMD, namely, GPIO6 to GPIO11 are connected to the integrated SPI flash integrated on the module and are not recommended for other uses.

## Appendix 6: Phase Failure details

### PHASE FAILURE PROTECTION DEVICES MKC-01, MKS-01, MKC-03, MKS-03, MKC-04

#### General

One of the common faults faced in industrial plants is over-heating and burning of 3 phase motors due to the phase failure. "Thermic-magnetic device" which is an essential element in motor protection is generally too slow due to both its electro-mechanical structure and the use of high current setting range to assure demarrage without tripping. Being designed to eliminate the above disadvantages, MKC-01 and MKC-03 Phase Failure Devices react within 0.2 seconds (fixed) against the following faults and take the motor out of service.

#### 1. Voltage Unbalance (Not Adjustable)

MKC-01 and MKC-03 have neutral connection, Unbalanced voltage for Phase-Neutral (fixed). When the value exceeds the 40% for MKC-03 and MKC-04 or 20% for MKC-01 and MKS-01 output relay switches-off the motor.

- Unbalanced voltage may occurred when:
    - The mains are loaded with unbalanced distribution.
    - One of the 3-phase of motor has lost. In this case, some amount of voltage which produced by other phases will be inducted on the lost phase. Amount of this value depends on both the motor type and amount of load.
- Output relay is activated when a phase has lost or an unbalanced phase-neutral value, which is occurred with any reason, is smaller than the Asymetrical value which is defined for the device. If this unbalanced voltage exceeds the adjusted Asymetrical value, output will release itself and motor will be Switched-off.
- In Applications; a proper device must be used regarding to the inducted voltage value in two-phase which are remained after the other one has lost.

$$\text{Asymmetry \%} = \frac{|V^L1 - V^L2|}{V_{\text{Ref}}} \times 100$$

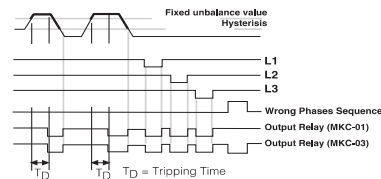
$$V_{\text{Ref}} = 220 \text{ VAC}$$

The voltage asymmetry causes the rise in motor temperature and a reduction of the rated motor power.

#### 2. Phase Sequence (MKC-03, MKS-03, MKC-04)

When the phase sequence is correct (L1, L2, L3 in clockwise direction) the output relay is activated; however, if the sequence is changed by any reason, the output relay switches OFF immediately.

#### Function Diagram



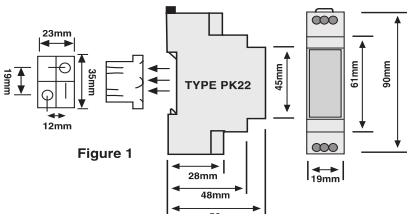
#### Precautions For Installation and Safe Use

Failure to follow those instructions will result in death or serious injury.

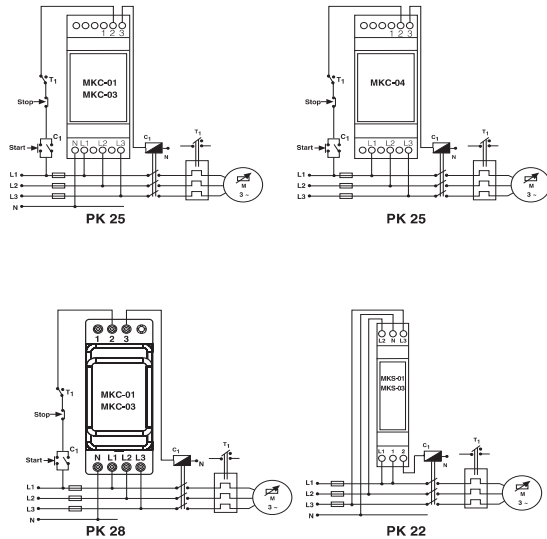
- Disconnect all power before working on equipment.
- When the device is connected to the network, do not remove the front panel.
- Do not try to clean the device with solvent or the like. Only clean the device with a dried cloth.
- Verify correct terminal connections when wiring.
- Electrical equipment should be serviced only by your compedent seller.
- Mount device to the panel.

No responsibility is assured by the manufacturer or any of its subsidiaries for any consequences arising out of the use of this material.

#### Dimensions



#### Connection Diagram



#### Technical Data

Rated Voltage (Un)	: Please look at labels on the device.
	: 3 phase and neutral 220-230 VAC
	: 4 Wires Star Connection (MKC-01, MKC-03, MKS-01, MKS-03)
	: 3 Phase 380 VAC
	: 3 Wires Delta Connection (MKC-04)
	: 3 Phase 220 V AC
	: 3 Wires Delta Connection (MKC-04)
Operating Range	: (0,9-1,1) x Un (MKC-04)
	: (0,8-1,2) x Un (MKC-01, MKC-03, MKS-01, MKS-03)
Rated Frequency	: 50/60 Hz.
Output Contacts	: 1 C/O, 8A, 250 V AC, 2000 VA, Cosφ=1 (MKC-01, MKC-03, MKC-04)
	: 1 NO, 8A, 250 V AC, 2000 VA, Cosφ=1 (MKS-01, MKS-03)
Warning LEDs	: LED output, normally ON (OFF for any fault)
	: ON LED1: On when supply voltage is present (MKC-01, MKC-03)
Tripping Time	: 0.2 sec.
Ambient Temperature	: -5 °C ; +50 °C
Protection Class	: IP 20
Dimension	: Typ PK 22 (MKS-01, MKS-03)
	: Typ PK 25 (MKC-01, MKC-03, MKC-04)
	: Typ PK 28 (MKC-01, MKC-03)
Installation	: Surface mounting or on the mounting rails.
	: Panel mounting with screws and adapter is possible. (Refer to Figure 1)
Weight	: 0.08 kg. (MKS-01, MKS-03)
	: 0.1 kg. (MKC-01, MKC-03)
	: 0.2 kg. (MKC-04)



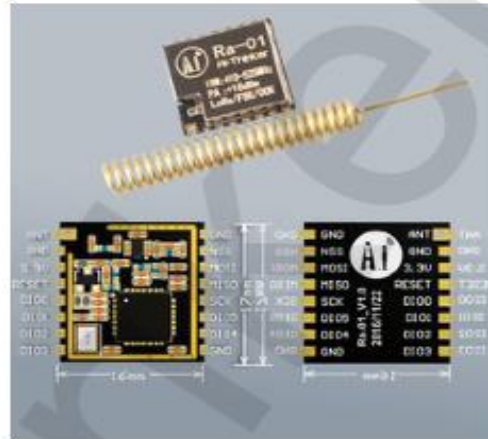
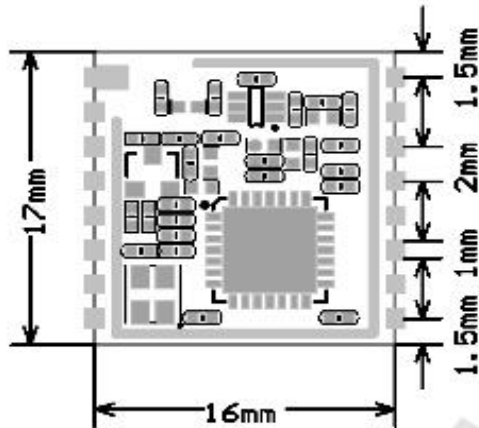
A4908 / Rev.4

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## Appendix 7: Ra-01 LoRa Module details



### Ra-01 LoRa Module



### Features

- LoRa™ spread spectrum modulation technology
- Receive sensitivity as low as -141 dBm
- Excellent resistance to blocking
- Supports preamble detection
- Supports half-duplex SPI communication
- Programmable bit rate up to 300Kbps
- Supports FSK, GFSK, MSK, GMSK, LoRa™ and OOK modulation modes
- Supports automatic RF signal detection, CAD mode and ultra high speed AFC
- Packets with CRC, up to 256 bytes
- Small package with double volume stamps

### Overview

Ra-01 can be used for ultra-long distance spread spectrum communication, and compatible FSK remote modulation and demodulation quickly, to solve the traditional wireless design can not take into account the distance, anti-interference and power consumption.

Ra-01 can be widely used in a variety of networking occasions, for automatic meter reading, home building automation, security systems, remote irrigation systems, is the ideal solution for things networking applications.

Ra-01 is available in SMD package and can be used for rapid production by standard SMT equipment. It provides customers with high reliability connection mode.

## Product Specifications

Module Model	Ra-01
Package	SMD-16
Size	17*16*(3.2 ± 0.1) mm
Interface	SPI
Programmable bit rate	UP to 300Kbps
Frequency Range	410-525 MHz
Antenna	Spring antenna with gain of 2.5 dBi
Max Transmit Power	18±1 dBm
Power (Typical Values)	433MHz: TX:93mA RX:12.15mA Standby:1.6mA 470MHZ: TX:97mA RX:12.15mA Standby:1.5mA
Power Supply	2.5~3.7V, Typical 3.3V
Operating Temperature	-30 ℃ ~ 85 ℃
Storage Environment	-40 ℃ ~ 90 ℃ , < 90%RH
Weight	0.45g

## Receive Sensitivity

Frequency	Spread factor	SNR	Sensitivity
433MHz	7	-7	-125
	10	-15	-134
	12	-20	-141
470MHz	7	-7	-126
	10	-15	-135
	12	-20	-141

Note: The above data are measured by the Semtech Shenzhen laboratory. The test conditions: power output 20dBm, bandwidth 125KHz.

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## **RESEARCH OUTPUTS**

**Output 1: Poster Presentation**

# Output 1: Poster Presentation Design

## Development of Intelligent Hybrid Power Transfer Switch to Support Optimization of Water Supply Scheme: Case of Arusha

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### Abstract

This study explores the use of an intelligent hybrid power transfer switch system model to improve the Ngarantoni Water Supply Scheme's operation. The model detects, transmits, and receives water level data, switches to the appropriate power source, and features automatic transfer switches and user safety modes. Experimental findings highlight its effectiveness and capabilities.

### Objective

#### Main Objective

To develop an intelligent hybrid power transfer switch to support optimal operation of water supply scheme.

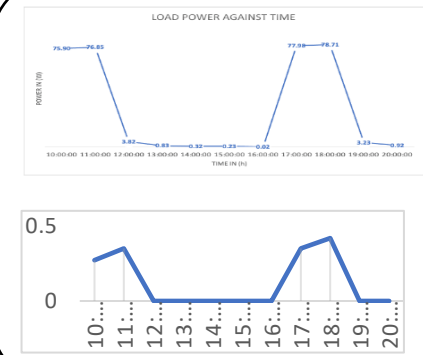
#### Specific Objective

- i. To study, analyze and set up the requirements and specifications of the intelligent hybrid power transfer switch.
- ii. To integrate the designed and developed system requirements for the intelligent hybrid power transfer switch.
- ii. To verify and validate the intelligent hybrid power transfer switch model

### Methodology



### Results



### Conclusion

To reduce excess costs incurred by electricity bills, the operation of booster pumps in the Ngarantoni water supply scheme has to be optimized. The utility's existing manner of operation is exceedingly costly. By establishing an automated system for booster pump power regulation and water level measurement, this suggested system intends to address some of the operational issues by automatically controlling the system.