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Analysis of Energy Consumption and Energy Saving Opportunity at Solar Powered Water Treatment Plant: A Case Study of Sundarighat Water Treatment Plant

by

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A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Analysis of Energy Consumption and Energy Saving Opportunity at Solar Powered Water Treatment Plant: A Case Study of Sundarighat Water Treatment Plant"** submitted by Umesh Kumar Mehta, in partial fulfillment of the requirements for the degree of Master of Science in Energy system planning and management.

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ABSTRACT

This study primarily focused on the fundamentals associated with energy saving opportunity at drinking water supply system. In Nepal water supply system is designed based the immediate requirement without proper study with the limited available resources. Sundarighat water treatment Plant treats the water from Nakhu Khola and pumped to major part of Kathmandu valley for distribution through the pumping system available at WTP. Pumping system at WTP consume most of the energy compared to other electrical load at the treatment plant. The technical status and performance of the equipment, machineries and accessories of pumping system are largely unknown as the evaluation of the system was not performed yet.

In this study, an analysis of the energy consumption by performing energy audit at WTP was done to find the status of electrical parameter for energy efficient operation of plant and identifies the opportunity to save energy and cost through pump size selection. A power quality analyzer and three phase clamp meter was used to analyze the patterns of electrical parameters. Hydraulic simulation software EPANET 2.2 was used for determination of pump size by analyzing the water transmission pipeline.

Specific Energy consumption of the plant found increasing over the years while treating and pumping the same amount (6 MLD) of water. For the given case of pumps, average efficiency found as 63.58 % which is less than the best efficiency (75%) of the pump. Correct size pumps for the given system provide the required efficiency with 355.96 kWh of electrical energy saving daily and NRS 662623.5 cost saving annually.

Hydraulic simulation of transmission network in EPANET 2.2 found that transmission pump oversized by 10.5 kW for the current operating condition with efficiency of 75%. Simulation result suggests the size of the desired pump having 1330 lpm discharge at 102.5 meter head and pump capacity 30 kW with operating efficiency of 75%.

ACKNOWLEDGEMENTS

It's a matter of great opportunity to forward this report on the project "**Analysis of Energy Consumption and Energy Saving Opportunity at Solar Powered Water Treatment Plant: A Case Study of Sundarighat Water Treatment Plant**". First of all, I would like to thank the 'Department of Mechanical and Aerospace Engineering' of Pulchowk Campus, Institute of Engineering, Tribhuvan University for the inclusion of research as the course of study, in which we are granted an opportunity to make a choice of any project of our interest as the thesis.

I would like to express my sincere gratitude to Asst. Prof. Sanjaya Neupane and Asst. Prof. Tek Raj Subedi, my project supervisor for their valuable guidance, constant support, and encouragement which have been really appreciable for the persistence of my thesis project.

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TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

LIST OF ACRONYMS

HP	Horse Power
kVA	Kilo Volt Ampere
kVAR	Kilo Volt Ampere Reactive
kW	Kilo Watt
kWh	Kilo Watt Hour
KUKL	Kathmandu Upatyaka Khanepani Limited
KVWSB	Kathmandu Valley Water Supply Management Board
NEA	Nepal Electricity Authority
PF	Power Factor
TOD	Time of Day
VFD	Variable frequency drive
WTP	Water Treatment Plant
LPM	Liter Per Minute

CHAPTER 1: INTRODUCTION

1.1 Background

Even while water makes up roughly 70% of the planet, only 2.5 percent of it is fresh, and only 1% of it is fit for human consumption because most of it is frozen in glaciers and snowfields. All told, just 0.007% of the water on Earth is usable for supporting and feeding the planet's 8 billion (National Geographic). Energy along with water plays important roles in the economic and social growth of any nation. People use water for various purposes like drinking, bathing, washing, cleaning, flushing and other day to day activities. Water consumptions per person per day vary with requirement, availability, quantity and quality of water. Millions of people live in emerging countries' rapidly expanding towns and cities without access to basic amenities like properly managed water and sanitary systems. Energy use was impacted by the worrisome rate of population growth and economic expansion worldwide (Abdelaziz, Saidur and Mekhilef, 2011). Planning for urban areas is not keeping up with population expansion. Poor health conditions and high wastewater pollution loads are caused by the majority of urban populations in developing countries not having access to water and sanitation due to lack of planning, funding, and infrastructure(Lyons, 2014).

Increasing population and urbanization increases the importance of advanced and safe water supply system. Water and energy are mutually dependent. Pumps in water distribution systems must run on electricity in order to supply end users with the necessary volume of water at an appropriate pressure. Water is required for a variety of processes during the extraction of energy from its sources. Most of the water pumps run on electricity or Diesel oil. Electric motors consume 46% of energy generated worldwide energy of which 22% energy of consumed by pumping systems(Arun Shankar *et al.*, 2016). Conventionally, electricity mostly generated by hydropower plant and fossils fuels has been supplied from national grid.

Several renewable sources of energy can be seen being used for water pumping. Photovoltaic panels utilize energy from sun to generate electricity which could be used to run the electricity operated water pumps. Solar powered pumping system is in increasing trend especially for the irrigation. Solar powered pumping system is also widely being used to supply of water for daily use in remote area where grid electrification is difficult. Household solar water heater mostly employing natural pumping can be seen on the top floor. Lots of research and development is in process to improve the solar panel energy capacity. Similarly many studies have been there for solar powered water pumping systems in many aspects to make it more reliable and efficient system.

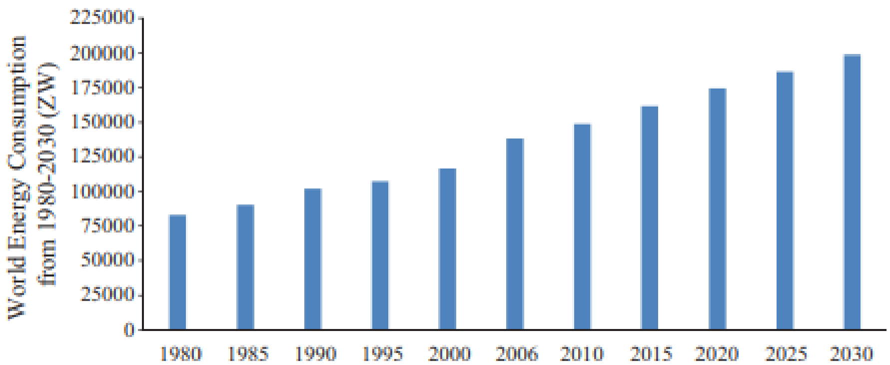

Figure 1: *Energy Consumption World Wide from 1990-2030*

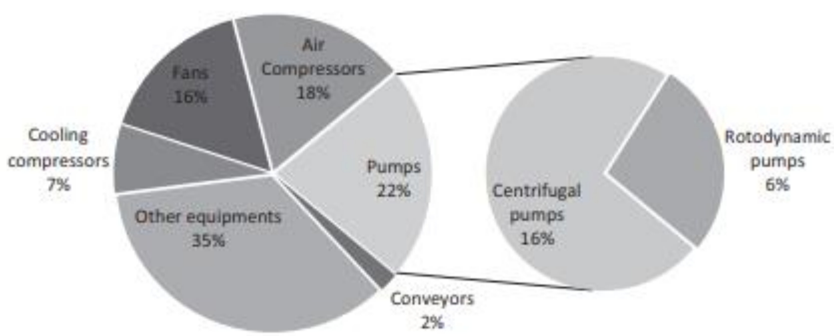

Figure 2: *Motor energy consumption for various applications*

The US Department of Energy examined pumping system components and the losses that were incurred are described in Table 1(Arun Shankar *et al.*, 2016) shows that maximum losses occurred in piping system followed by pumps and motors for the given pumping system.

Table 1: Losses in Pumping System

S.N.	Component in pumping System	Efficiency (%)	Losses (%)
1	Piping system	50-60	40-50
2	Pumps	85-90	10-15
3	Coupling	~99	~1
4	Motors	>90	<10
5	VFD cables	~98	~2
	VFDs	95-98	2-5
7	Transformers	~99	~1

1.2 Problem Statement

Sundarighat Water Treatment Plant located one kilometer from Balkhu Chowk on the way to Chobhar, besides Dakchinkali road. The Source of raw water for Sundarighat WTP is from Nakhu Khola and it processes the water by sedimentation process and pressure filtration method. The treated water from Sundarighat WTP is supplied to major part of Kathmandu valley through the pumping system at Sundarighat WTP. The Dhobighat solar plant and the NEA grid provide the electricity needed to run the Sundarighat WTP and pumping system

The Dhobighat Solar Plant was commissioned at the end of June 2012. The Japanese government's Japan International Cooperation Agency (JICA) provided funding for the solar project. The project's goal is to show how renewable energy can supplement the country's electrical supply. The project uses a photovoltaic (PV) generation system to generate 680.4 kW of solar energy near the Dhobighat waste water treatment plant on the bank of the Bagmati River. The electricity generated by the plant is being supplied to the nearby Sundarighat WTP of KUKL and the surplus energy is transferred to the grid distribution network of NEA. The solar plant is under the KVWSMB and the electro-mechanical branch of KUKL is operating the plant since its commissioning.

At Sundarighat WTP, pumping system consume most of the energy compared to other electrical load at water treatment plant. The technical status and performance of the equipment, machineries and accessories are largely unknown as the evaluation of the system was not performed yet. So the aim of the study is to analyses the electrical and mechanical equipment to identify the opportunity to improve the overall operating efficiency and recommend necessary action to run more efficiently. As the surplus energy from solar plant is sold to NEA, every unit of energy saved through efficient operation of pumping system will be the revenue to KUKL.

1.3 Objective

1.3.1 Main Objective

The main objective of this research is to assess the electricity consumption of a water treatment plant and identify opportunities to save energy through hydraulic simulation.

1.3.2 Specific Objective

- To determine the energy consumption pattern at Sundarighat WTP.
- Perform a comprehensive energy audit for efficient operation of pumping system.
- Identify the energy saving opportunity by hydraulic simulation model developed in EPANET 2.2 for the selection of optimal operating parameters under given condition of the water supply system.

1.4 Limitation of Study

- Hydraulic simulation in EPANET of the distribution network is not possible due to limitation of data related to pipe network.

- Performance analysis of Dhobighat solar power plant is not in the scope of this study.
- This study is limited to analysis of energy consumption in the treatment plant and identifies the opportunity to save the energy.

CHAPTER 2: LITERATURE REVIEW

Various papers related to solar powered pumping system, methods of energy auditing in pumping system, energy & cost saving potentials in pumping system, use of hydraulic simulation software EPANET 2.2 in selecting pump parameters and cost benefit analysis of various techniques to be incorporate in this study are reviewed.

2.1 Solar Powered Pumping System

Pumping water is universal need around the world and photovoltaic power usage for this purpose is rising. A solar-powered pump is one that is powered by the sun. When used properly, a solar-powered pump can be both cost-effective and environmentally beneficial. The system runs on electricity produced by photovoltaic (PV) solar systems. The motor pump set is powered by the electricity produced by the photovoltaic array from solar energy. Solar water pumping system can be used for various purposes like irrigation, drinking water supply, watering in garden, to run sprinklers and so on.

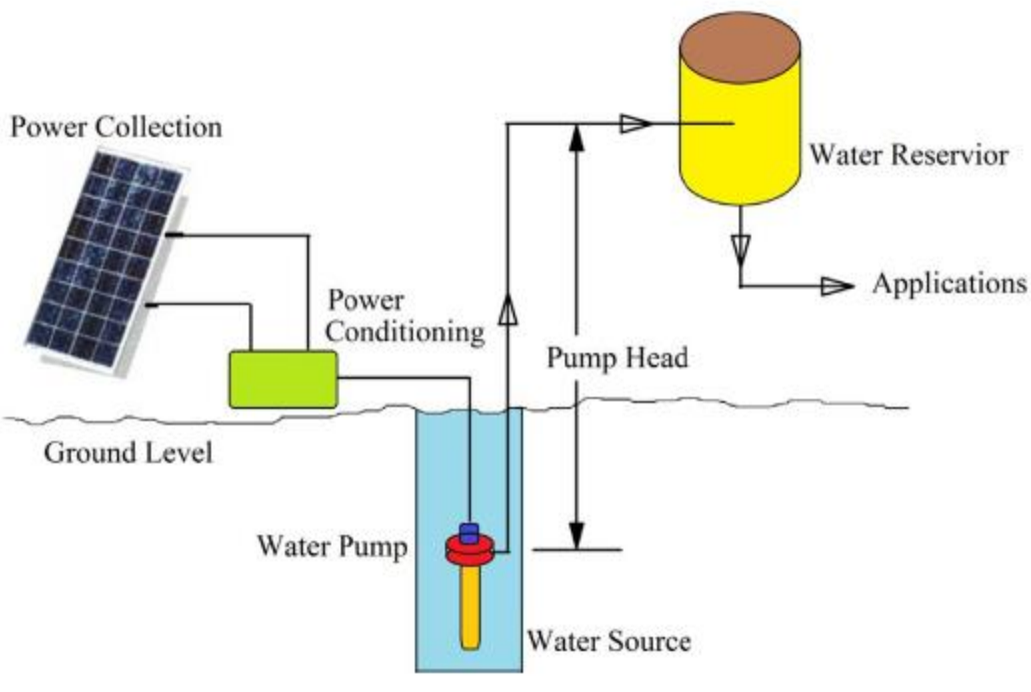

Figure 3: Schematic Diagram of solar powered water pumping system

Figure 3(Aliyu *et al.*, 2018) describes the process of the generalized water pumping system powered by solar, in which electrical energy generated from solar is used run electric water pump after power conditioning. The water from the water source pumped to reserved tank and from where water is being used for its applications.

2.2 Solar power plant at Dhobighat

The Dhobighat Solar Plant is a photovoltaic (PV) generation system with a rated 680.4 kW solar power capacity. The electricity generated by the plant is being used to run to the system of Sundarighat Water Treatment Plant of KUKL and the surplus energy is sold to Nepal Electricity Authority as per the PPA between owner of assets 'KVWSMB' and NEA. The Electro-Mechanical Branch of KUKL is managing its efficient operation since commissioning. Sundarighat WTP uses the energy from NEA grid and energy produced by the Dhobighat solar plant is fed to NEA grid. The energy produced by solar plant is found more than the energy utilized by WTP.

2.3 Tariff Structure of NET Metering

In Nepal, the Nepal Electricity Authority is responsible for revenue collection and consumer services. Here solar plant produce excess of energy than required at Sundarighat water treatment plant and is being purchased by NEA and in case of deficient of energy production by solar plant, NEA will charges for every unit of deficient energy required by Sundarighat WTP as per the PPA between KVWSMB and NEA for this particular case of community based water utility as described in Table 2.

Table 2: PPA between KVWSMB and NEA

S.N.	Descriptions	Rate(per kWh)
1	Energy delivered from solar to NEA	5.1
2	Energy purchased from NEA	6.2

For small, medium and large-scale industries has two part of tariffs. The two-part tariff consists of active power and apparent power, and active power is kWh charges whereas apparent power is maximum demand charge. The tariff structure(NEA, 2021) of the TOD meter for community based water utility is as seen below.

Table 3: Nepal Electricity Authority Tariff Structure of Time of Day Meter.

S.N.	Consumer category	Demand charge per KVA (NRs.)	Peak hour (5 pm -11 pm) per unit(NRs.)	Off-peak hour (11 pm - 5 am) Per unit (NRs.)	Normal hour (5 am - 5 pm) per unit (NRs.)	Remarks
1	For 11 kV	0	6.3	3.4	4.7	Wet season
2	For11KV	0	6.3	4.7	4.7	Dry season

2.4 Water Treatment Plant

Generally Water treatment plant has the facility to treat both groundwater and surface water. Well facilitated WTP has Bio-filters, flocculation chamber, sedimentation chamber, and filtration chamber with pre chlorination, post chlorination, back wash system for the treatment of water. Bio filters are used only for groundwater to treat biological components. The water from the bio-filter and surface water meet at the inlet distribution chamber, where the water is pre-treated with bleaching powder and alum. Then, the water goes to the flocculation chamber where formation of coagulation occurred by reacting with bleaching and alum. At sedimentation chamber coagulated particle settled down at bottom and remaining left coagulates filtered during the filtration. Post chlorination is done depending on the free residual chlorine left in treated water. Water after filtration stored in the reservoir tank from where it is being supplied as per requirement.

2.4.1 Sundarighat Water Treatment Plant

Sundarighat Water Treatment Plant treats the ground water from Nakhu Khola and it processes the water through sedimentation process and pressure filtration method with pre and post chlorination. Alum is used to segregates the dissolved particle and mud before sedimentation. The treated water from Sundarighat WTP is distributed to many area of Kathmandu valley using the pumping system available.

2.5 Energy Efficiency enhancement opportunity in Water Supply System

Water supply system consume significant portion of global energy consumption. This energy consumption in water supply system related to water production, collection, treatment, transportation and distribution of water entails a large amount cost and these costs are liable to minimized with and/or without reduction on energy consumption. Enhancing the energy efficiency of water supply systems can begin with basic leakage control monitoring and progress to more intricate tasks like predicting water demand, optimizing pumping systems, optimizing production and storage systems, and real-time operation (Coelho and Andrade-Campos, 2014)

Leakage causes about 30% of the water loss, which translates to an equivalent loss of energy. Numerous things can lead to energy losses in pumping systems, such as inefficient pump stations, improperly installed pumps, a lack of scheduled or routine maintenance, head loss in outdated pipelines, network bottlenecks, high pressures, and inefficient operation methods(Jamieson, 2007).

Improvements in energy efficiency in water supply systems can achieved with(Jamieson, 2007):

- Pump stations design improvement,
- Pumping system design improvement,
- Variable speed drives (VSD) installation,
- Proper pump selection,
- Efficient operation of pumps and
- Leakage reduction

Various opportunities for the enhancement of the energy efficiency in water pumping system can be studied by classifying the methods into the following different classes as shown in Figure 4.

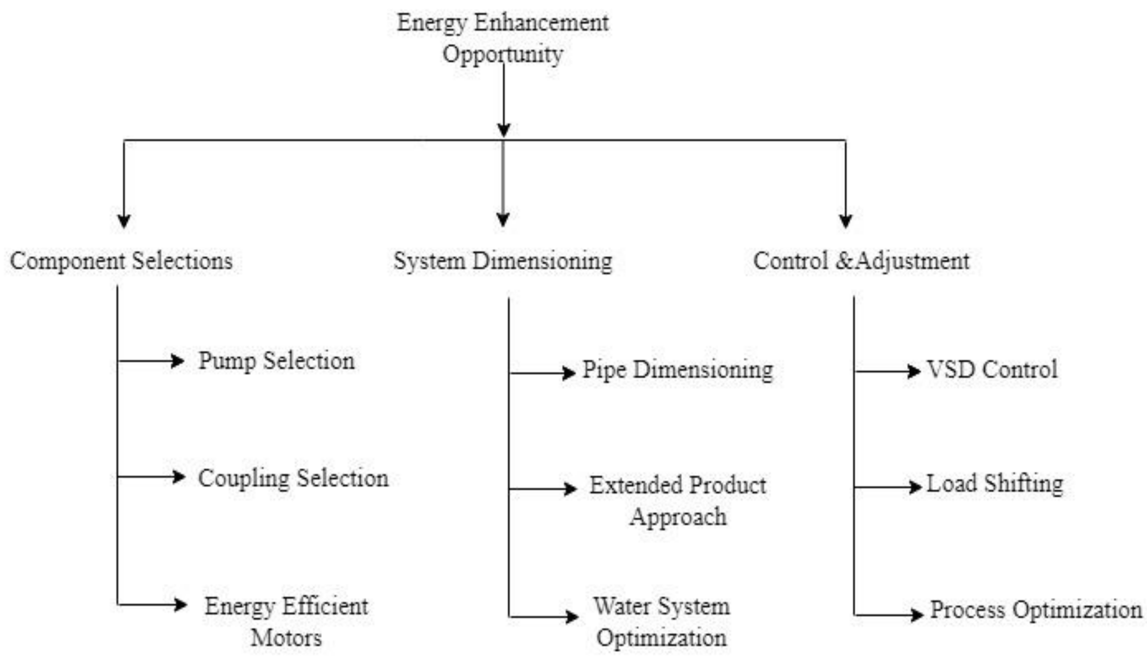

Figure 4: Energy enhancement opportunity in water supply system

2.6 Components in Studied Water Supply Systems

Water pumping system comprises of major equipment like pumps, motor, variable frequency drive, valves, electrical operating system and other fittings such as volumetric water meter & pressure gauge.

2.6.1 Pump

A pump is a device that uses mechanical action to move liquids, gases, or slurries. It is typically powered by electricity or diesel/gasoline, which is then converted into hydraulic energy. Solar powered pump is in used in remote area. Pumps are used worldwide to supply water for agricultural, municipal, industrial, fire protection and residential applications. Many kinds of pumps are used in distribution systems. Two types of pumps are commonly used in potable water pumping applications: vertical turbine pumps, line shaft and submersible types, or centrifugal horizontal or vertical split case pumps designed for waterworks service(Guyer, 2012)

A hydraulic network analysis of the distribution system will help determine the necessary capacity of a potable water pump selection. Computer programs can be used to simulate the pumping requirements for different design conditions at one or more locations for varying flow rates over extended periods of time(Guyer, 2012). This data will be used to design the pump station, including the piping systems for the suction and discharge. The pump's operating capacity is indicated by the intersection of the system head curve and the pump performance curve(Guyer, 2012). Therefore, it is crucial to choose pumps that will function safely and close to the optimal efficiency point under both high and low system pressure scenarios.

Inefficient pump stations can be caused by the oversize of the pump capacity. The majority of current pump systems are oversized, with many of them being over 20% oversized, which presents a chance for the WSS to become more energy-efficient (Coelho and Andrade-Campos, 2014).

2.6.2 Electric Motor

Electric motors are used to drives the pump for water supply and distribution. Motors should be selected with sufficient capacity to drive the pumps. The most commonly used types of industrial electric motors are induction motors, DC motors, and synchronous motors. AC motors are generally preferred over DC motors due to their lower cost and better speed control with the use of a VFD.

2.6.3 Variable Frequency Drive (VFD)

A variable frequency drive (VFD) modifies the power supply's frequency and voltage to regulate the speed and torque of an AC motor. It can also regulate the acceleration and deceleration of the motor during start-up and stop, respectively. It save energy and improve system efficiency by matching the speed and power of the motor to process requirements. Larger pumps will only be given consideration for variable-speed devices if a thorough economic analysis supports their use (Guyer, 2012). Variable Frequency Drive for centrifugal pumps can operate with fixed pressure and variable flow or fixed flow and variable pressure (Coelho and Andrade-Campos, 2014). A variable frequency drive could reduce pumping energy consumption by 10% to 20% (Taylor and Geem, 2009). A 10% drop in pump speed can result in a 27% reduction in energy usage (Kang and Lansey, 2012).

2.6.4 Valves

Gate, globe, and angle valves, cone, butterfly, ball, check, and relief valves are among the valves used in the pump station piping system. The best valves for controlling flow to provide the required pressure or flow rate are globe, ball, cone, and butterfly valves. Vertical piping will not make use of check valves. From simple hand-operated valves to highly sophisticated automated flow control or pump speed control systems, pump control systems come in a variety of forms(Guyer, 2012). A pumping system also have non return valve that is being used to protect the pump water hammer due back pressure. Air releasing valves are used to release any trap air inside the pipeline.

2.6.5 Electrical Operating System

Electrical operating system consists of connection box, distribution board and starter (DOL/ Star-Delta/ ATS). Efficient electrical operating equipment must be adopted to avoid the frequent failure of electrical part and energy loss in terms of heat dissipation from the electrical system.

2.7 Hydraulic Simulation

Water supply system must be a system of engineered hydrologic and hydraulic components which will supply water at the best economical way. Hydraulic simulation helps in research and analysis of the hydraulic system with and without integration of other software.

Some research and analysis with the hydraulic simulation EPANET software in the field of water pumping with their results are as follows.

Using the EPANET hydraulics engine, the VSPM (Variable Speed Pivot Model) was created to conduct hydraulic and energy analyses of center pivot systems. With specific energy consumptions of 0.214 and 0.244 kWh m^{-3} of distributed water obtained for the variable speed and fixed speed of the pumping station, respectively, the results show a reduction in energy consumption of 12.2%(Dunca *et al.*, 2017).

(Zimoch *et al.*, 2021) found the wide use of numerical, hydraulic models, among others, for the needs of the sustainable oversize water supply systems management in order to improve energy efficiency. It also found that use of numerical simulation model EPANET 2.0 for the selection of optimal operating parameters under changing conditions of the water supply system. The conducted simulations indicate that the largest reduction of energy consumption was obtained after the introduction of VFD-type devices. It also help in the determination of critical operation zones of the water supply system, taking into account the optimization of pumping systems. Analysis of the level of water losses accompanied by the identification of their source, analysis of water supply network failure rate, analysis, and classification of leakage levels.

(Baranidharan and Singh, 2022) offers the best switching method to maximize energy savings for variable speed pumping stations with multiple parallel pump combinations. The suggested ideal control system is made with the goal of reducing the pump system's overall losses. In a Matlab Simulink environment, the effectiveness of the suggested method is examined on a real-scale multi-parallel pump drive system, and experimental validation is carried out in a laboratory prototype. The recommended method increases power savings and can be customized for different types of pumping applications.

(Halkijevic, Vukovic and Vouk, 2013) provides the optimal switching strategy for variable speed pumping stations with multiple parallel pump combinations in order to optimize energy savings. The overall losses of the pump system are intended to be decreased by the recommended optimal control system. The efficiency of the proposed approach is investigated on a real-scale multi-parallel pump drive system in a Matlab Simulink environment, and experimental validation is performed in a lab prototype. The suggested approach reduces power consumption and is adaptable to various pumping applications.

(Luna *et al.*, 2019) developed a hybrid optimization method to improve the energy efficiency of a water supply system. A genetic algorithm was used to optimize the pumping schedule during the day and evaluate the solution with a model of the water network developed in the hydraulic simulator EPANET. It is found that optimizing the pump scheduling can improve the energy efficiency up to 15% in average (maximum of 25%) comparatively to the real operation.

VASPCALM module(Vouk, Nakic and Halkijevic, 2018) allows for easy and effective analysis of the power consumption of pump operation with frequency regulation when integrated with EPANET. Its implementation is tested on Velika Gorika's (Croatia) real water supply system, and the results show that the minimum night flows can be reduced from 75 l/s with unregulated pump operation to 60 l/s with frequency regulation to constant outlet pressure, or even to 45 l/s at proportional output pressure. This is what happens when the pump outlet pressure is reduced from a level of 46–66 m with uncontrolled pump operation to either a constant 46 m outlet pressure or a proportionate 27–30 m outlet pressure range.

(Sperlich *et al.*, 2018) using MS visual basic for applications, EPANET was coupled with MS Excel and a genetic algorithm to identify the most energy efficient combination of pump speeds. For low and moderate flow scenarios, energy savings in the range of 20% compared to nominal speed operation can be achieved. These findings were confirmed by a monitoring campaign in the well field.

CHAPTER 3: RESEARCH METHODOLOGY

The research methods used include data gathering, energy audits and hydraulic simulation in EPANET 2.2. The initial phase involved site visits, followed by data collection about energy-consuming devices and areas where energy savings could be achieved. The research also involved analyzing efficient techniques.

3.1 Overview

The energy consumption of a water treatment plant is determined by conducting a detailed energy audit using energy measuring instruments. Analytical analysis of energy consumption is performed using Microsoft Excel. The theoretical framework of the research methodology is plotted in Figure 5.

3.1.1 Walk through Audit

- Identify connected loads by interviews with supervisor of WTP and inspection of pumps
- Determine the working hours of pumps and other loads
- Measure the discharge of water during water supply
- Collection of monthly energy produced data from solar and energy received from NEA
- Time required for walk through audit is 2 to 3 days.

3.1.2 Midway Audit

- Collection the data of voltage, current, average power factor, KWh consumption in each time slots from single meter load survey and further analysis using above data.
- Specific energy consumption
- Time required for half-way audit is 2 to 3 days

3.1.3 Detail Audit

- With the help of power quality analyzer record several average power factor, measured active power, system efficiency and pump efficiency.
- Finding the annual saving from the corrected power factor.
- Calculation of payback period for installation capacitor bank.
- Time required to experiment and analyzing data required date seven days.

3.2 Electrical Energy Consumption

It is calculated with rated power of the load (p) and operating time (t) using equations:

$$E = p \times t \quad (1)$$

Monthly energy cost can be calculated as

$$E_{mc} = E_m * C_{kWH} + E_{max} * C_{kVA} \quad (2)$$

Where E_{mc} is total monthly bill, E_m is the total energy consumed in one month, C_{kWH} *is* tariff per unit energy consumption and E_{max} is maximum demand and C_{kVA} is demand charge per unit energy consumption.

3.3 Electrical Energy and Cost Saving

Annual energy saving:

$$E_{saved} = (E_{old} - E_{new}) \times 12 \quad (3)$$

Where E_{saved} is total annual energy saved, E_{old} is total energy consumption before efficient method and E_{new} *is the* total energy consumption after efficient method.

Annual money saving:

$$M_{saved} = E_{saved} \times E_{pkwh} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where M_{saved} is total annual energy bill saving, E_{pkwh} is per unit cost of energy

Load factor is given by,

$$L.F = \frac{Actual\ load}{Approved\ load} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5)$$

Relation between power-factor (cosβ), KVA and kW is,

$$kW = kVA * \cos\beta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$kVAR = P * (\tan\beta_1 - \tan\beta_2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where kVAR is the reactive power required for power factor improvement, P is active power and β_1 and β_2 are phase angles before and after implementation of capacitor banks.

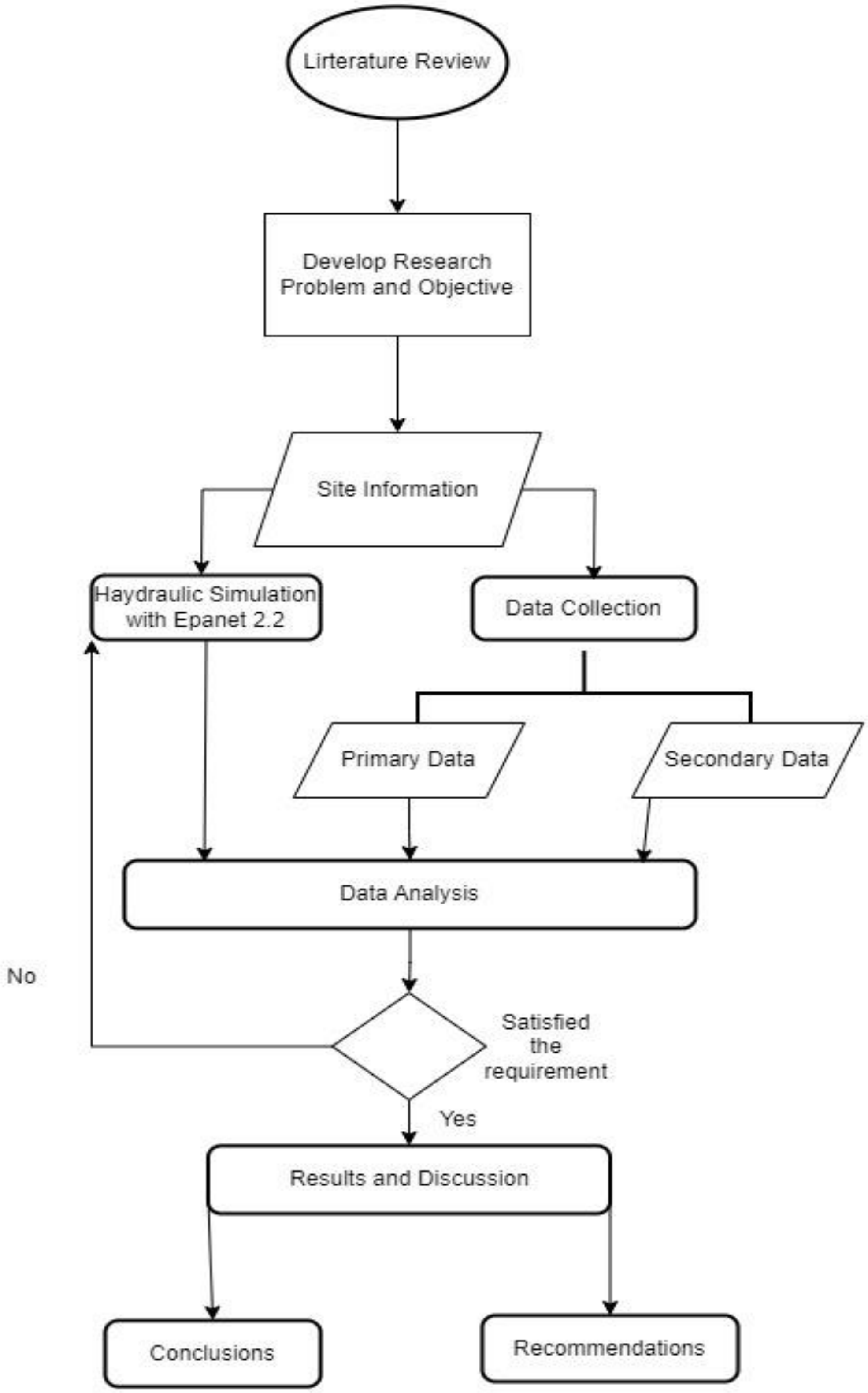

Figure 5: Theoretical Framework of Research Methodology

3.4 Experimental Setup

Power quality analyzer is used to extract the electrical parameters and is being setup as shown in Figure 6 the at the main distribution panel board.

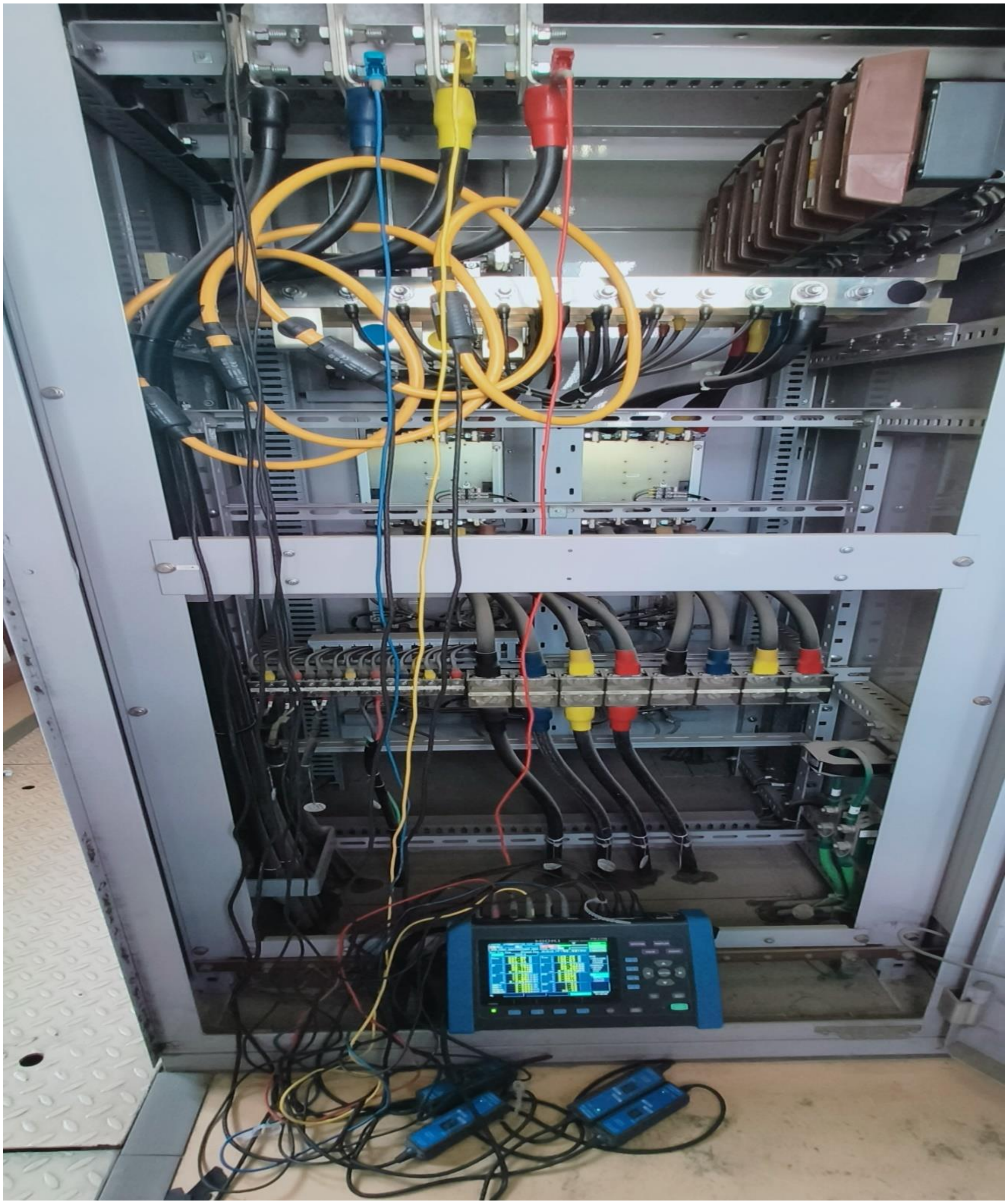

Figure 6: Power Quality Analyzer Setup

Three phase clamp meter is used to measure the electrical parameter of individual pumps and is being setup as shown in Figure 7.

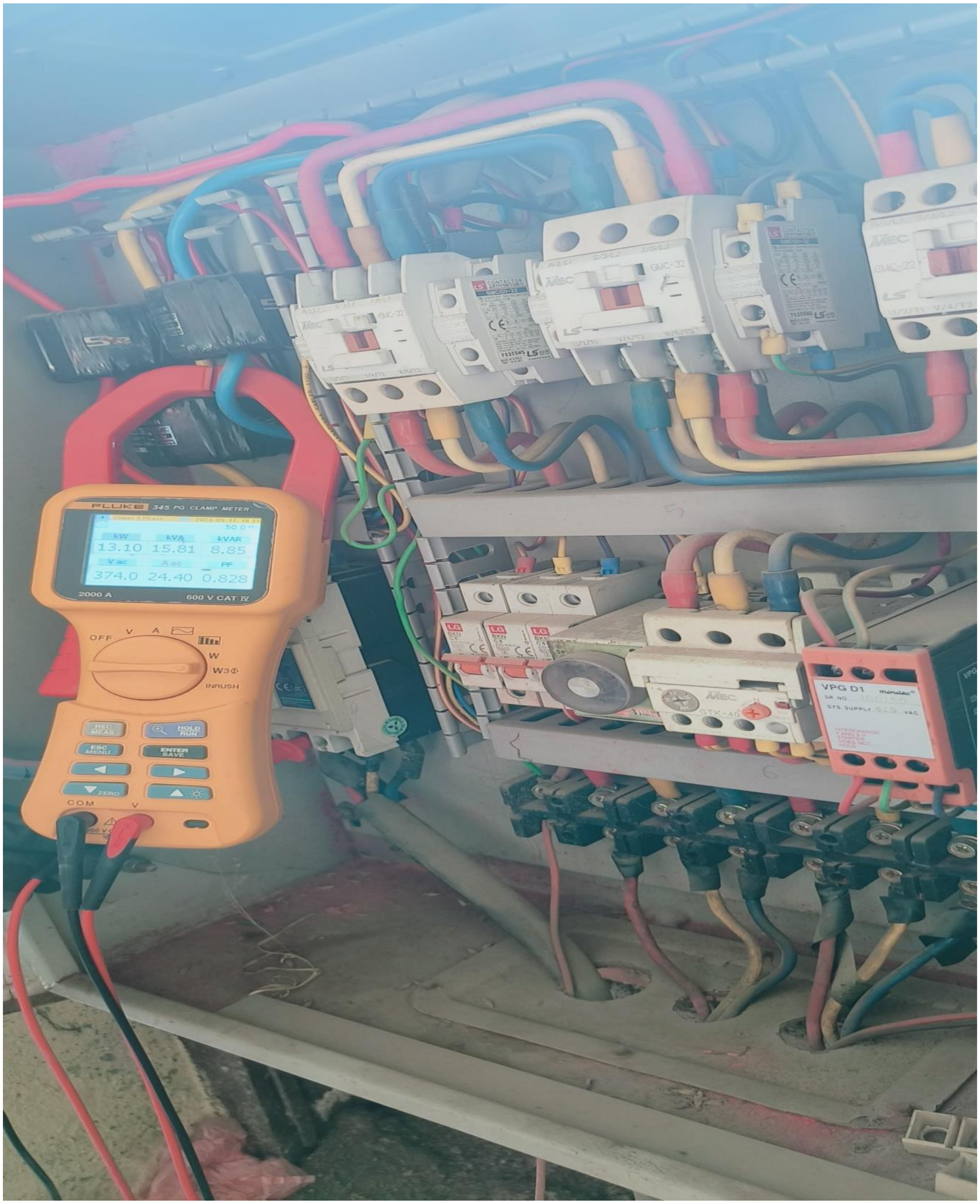

Figure 7: Three Phase Clamp Meter Setup

3.5 EPANET 2.2

The public domain program EPANET is used to model water distribution systems all over the world. It can be applied to a wide range of distribution systems analysis tasks and was created as a tool for comprehending the flow and destiny of drinking water constituents within distribution systems. EPANET is currently used by engineers and consultants for the following purposes: designing and sizing new water infrastructure; retrofitting aging infrastructure; optimizing the performance of tanks and pumps; lowering energy consumption; looking into issues with water quality; and being ready for emergencies. Additionally, it can be used to assess resilience to security risks or natural disasters and model contamination threats(EPA US, 2020).

EPANET assists water utilities in preserving and enhancing the quality of water that is provided to customers. It can be used for the following(EPA US, 2020):

- Design sampling programs
- Study disinfectant loss and byproduct formations
- Conduct consumer exposure assessments
- Evaluate alternative strategies for improving water quality
- Modify pumping and tank filling/emptying schedules to reduce water age
- Use booster disinfection stations at key locations to maintain target residuals
- Plan and improve a system's hydraulic performance
- Assist with pipe, pump, and valve placement and sizing
- Energy minimization
- Fire flow analysis
- Vulnerability studies

3.6 Site Location

Sundarighat Water Treatment Plant located at co-ordinates of 27°40'28''N, 85°17'29''E and one kilometer from Balkhu Chowk on the way to Chobhar, besides Dakchinkali road. The geographical map of sundarighat WTP is shown in *Figure 8*.

Figure 8: Sundarighat water treatment plant

Dhobighat solar plant is located at co-ordinates of 27°40'17"N, 85°17'40"E, bank of Bagmati River nearby Dhobighat waste water treatment plant in Bagmati province. The geographical map of Dhobighat solar plant is shown in *Figure 9*.

Figure 9: Dhobighat solar power plant

CHAPTER 4: RESULTS AND DISCUSSION

Initially, a walk-through survey is conducted in the solar and water treatment plants to collect data on electrical energy flow, treatment methods, connected loads, and load operation schedules for the week. In the detail phase audit, data is collected, process flow and energy utility data is prepared using power quality analyzer and three phase clamp meter. Hydraulic simulation using EPANET 2.2 is performed for a given transmission system to determine the pump size by integration with Google earth and result is verified with the actual at site.

4.1 Load Analysis of Water Treatment Plant

The following were identified as the plant's major connected loads:

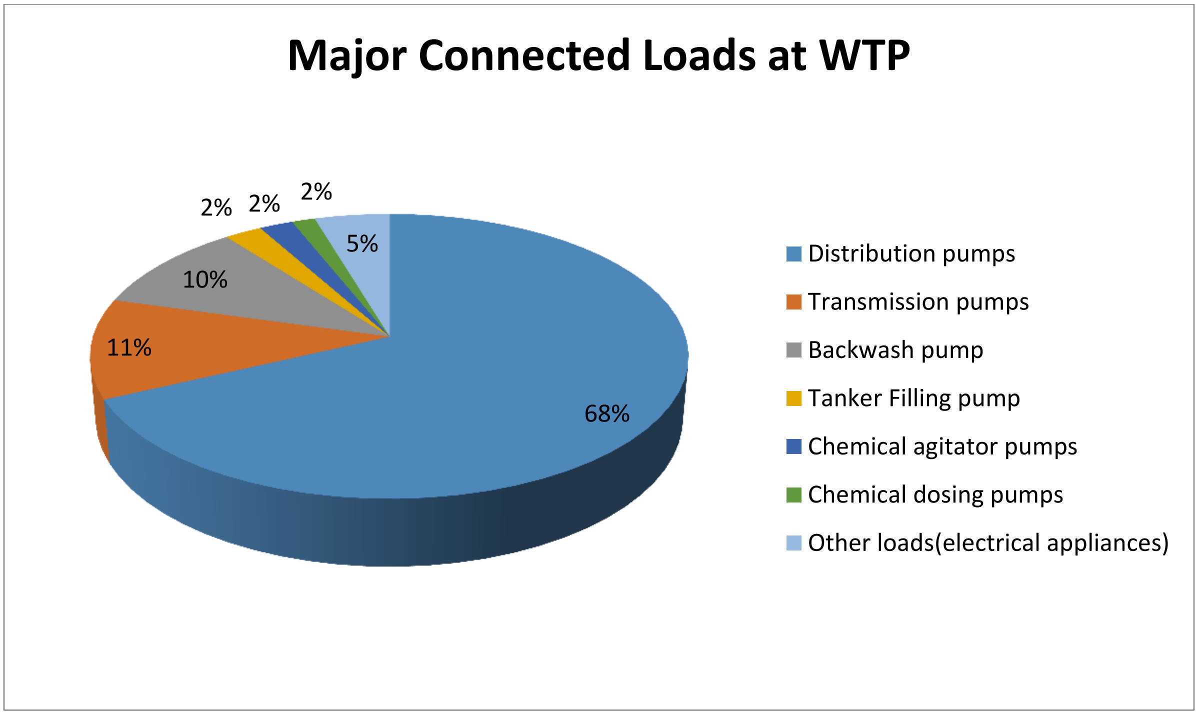

Figure 10: Major Loads Connected at Plant

Major connected loads found in Sundarighat water treatment plant with purpose and schedule of loads are briefed in the appendices (Table 14). Distribution pumps constitute the major portion of the loads and accounts for 68 percent of total connected loads at plant. Transmission pump is the second most loads in the plant and run for 4-5 hours daily. In this study the electrical parameter of the individual pump during running condition has been evaluated using three phase clamp meter. Power quality analyzer is used analyze the electrical parameter of the complete system.

4.2 Electrical Energy Flow Diagram

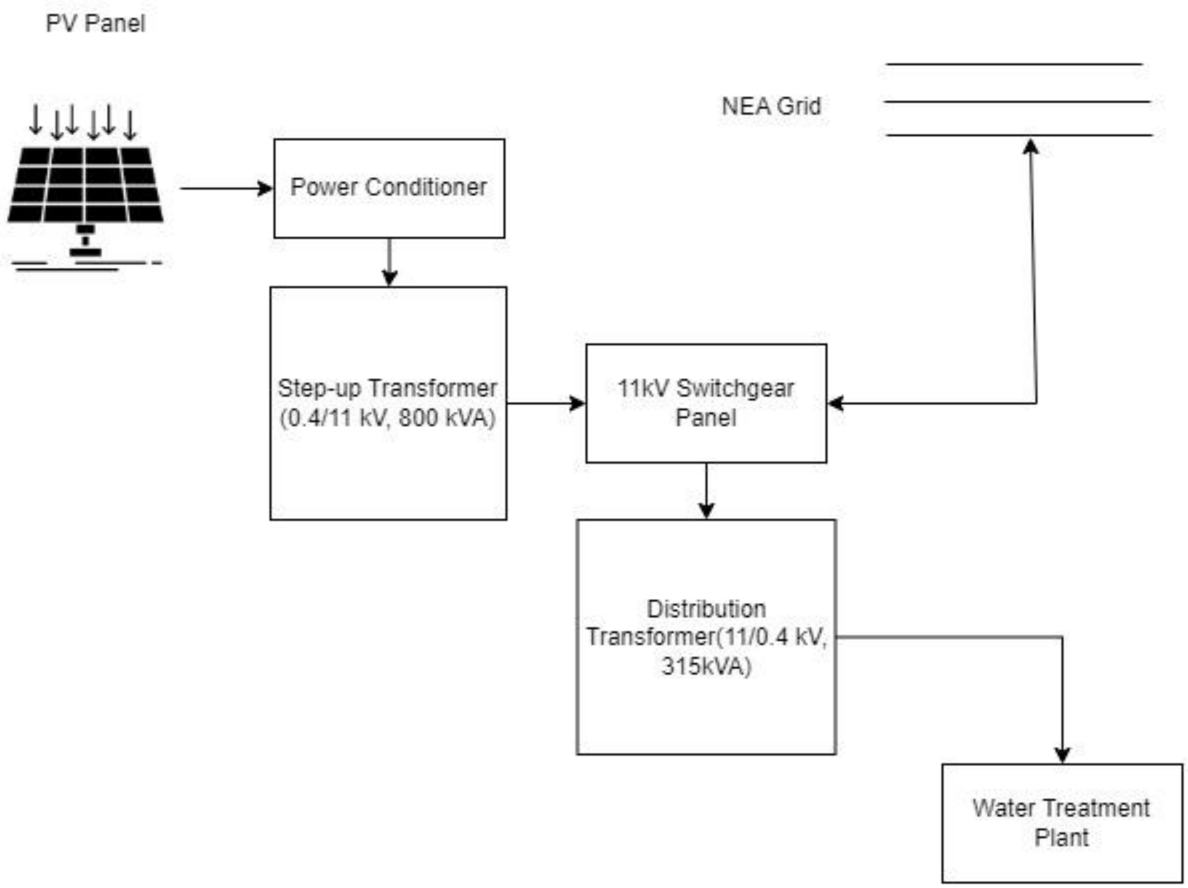

Figure 11: Electrical Energy Flow Diagram

4.3 Energy Production and Consumption Analysis

Annual accumulated energy production from solar plant and the energy consumed at Sundarighat WTP is compared and the annual surplus energy is calculated as shown in Figure 12.

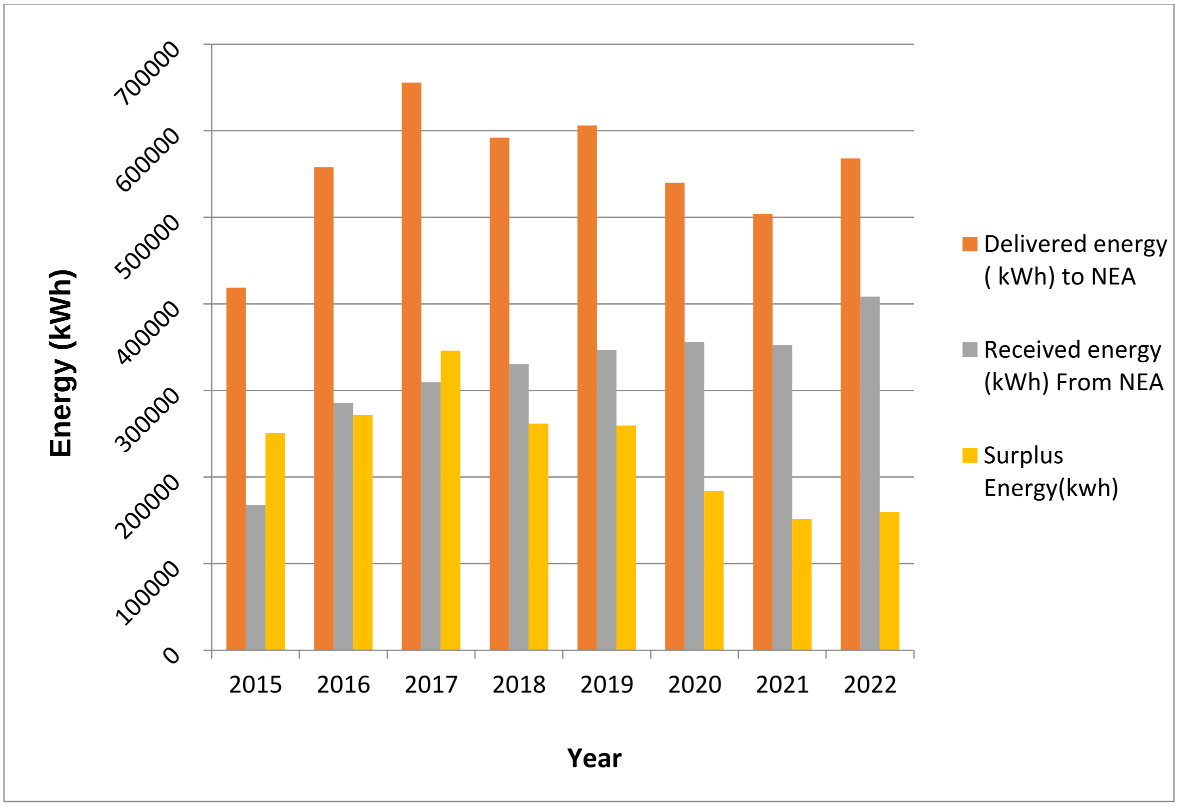

Figure 12: Energy production, consumption & surplus energy

4.4 Specific Energy Consumption and Specific Pumping cost

The energy consumed per cubic meter of water at the plant is known as specific energy consumption, and the cost incurred per cubic meter of water at the plant is known as specific pumping cost. The plant is handling 6000 cubic meter of water daily. The specific energy consumption and specific pumping cost of the plant found increasing over the years. Average specific energy consumption is 0.187 kWh per cubic meter and specific cost is NPR 0.95 per cubic meter for the year 2022 which were only 0.077 kWh per cubic meter and NPR 0.39 per cubic meter for the year 2015 respectively. The reason for this is the inefficiency in the pumping system and expansion in the distribution network based on immediate requirement without proper design over the years to account for water to the increasing population.

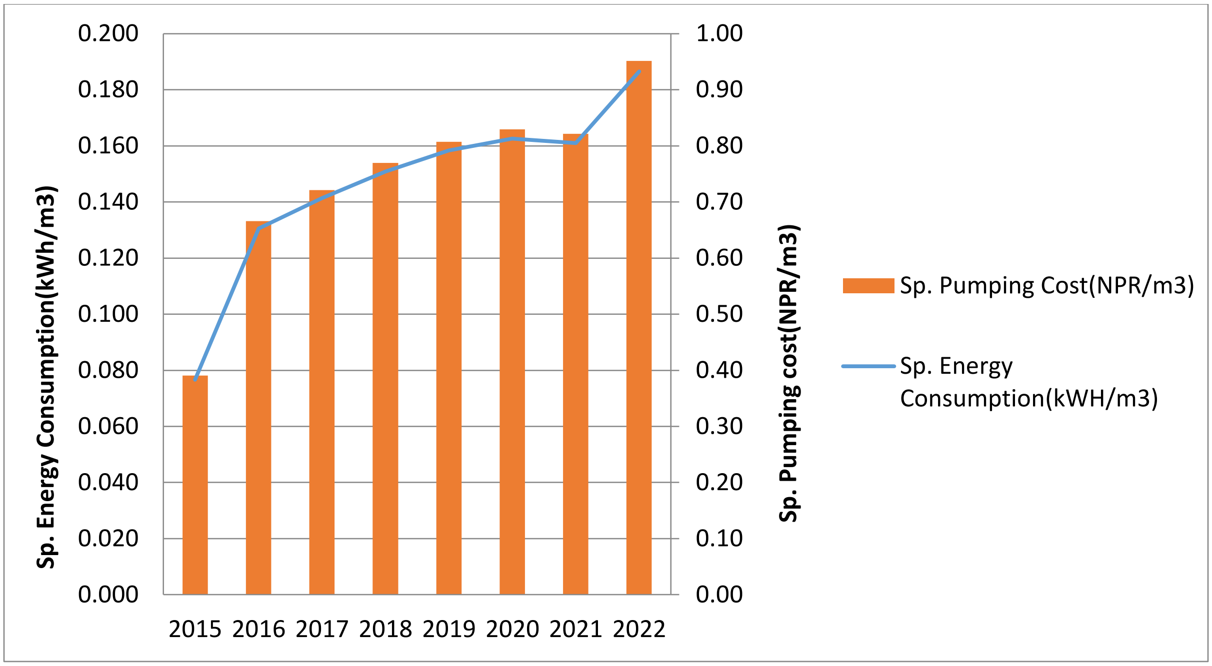

Figure 13: Specific Energy Consumption and Sp. Pumping Cost

4.5 Electrical Parameters of the Plant

Electrical parameters for the plant, including phase voltage, line voltage, line current, active power, apparent power, reactive power, PF, and frequency, are measured with the help of a power quality analyzer. These parameters are at the main distribution panel board to know the status of electrical parameter as a whole WTP. The data has been taken for 42 hours with the help of power quality analyzer. The details of the data are included in the appendices. The analysis of the various electrical parameter for the 24 hours are described in details the following section.

4.5.1 Power Factor of Plant

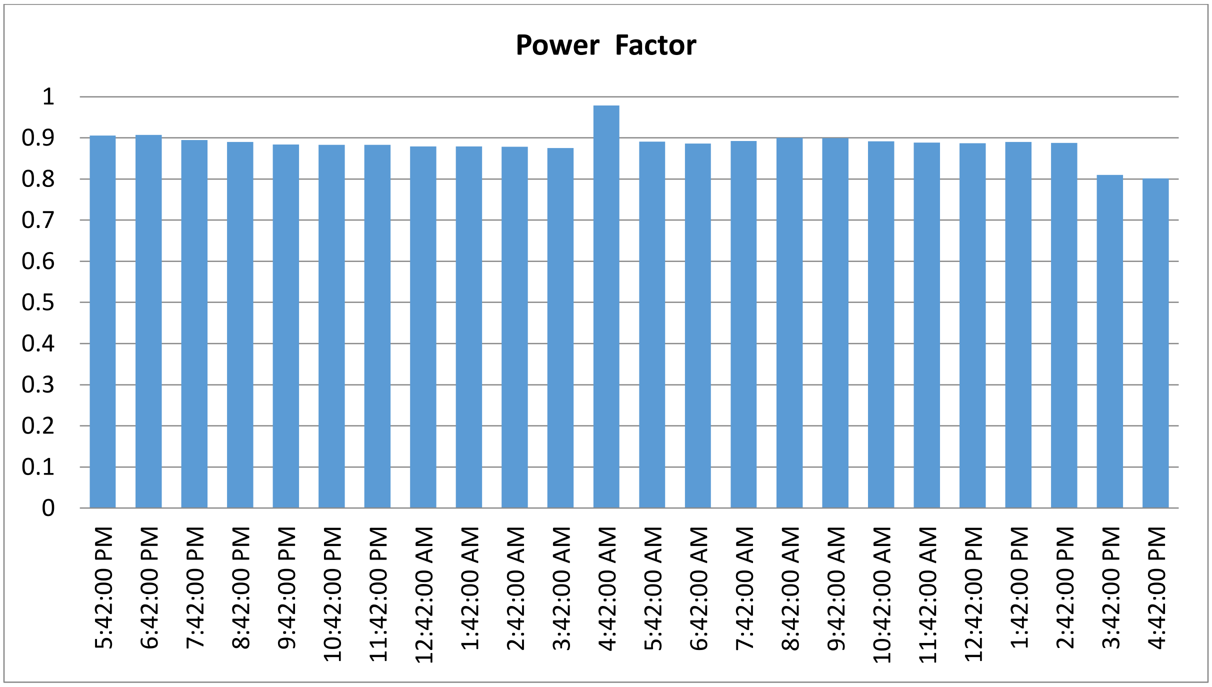

Figure 14: Power Factor of Sundarighat Water Treatment Plant

The power factor of the sundarighat WTP is found as almost constant as 0.89. The power factor is varying in the range of 0.813 to 0.98. There is still opportunity to improve the PF to make it up to constant value of 0.99 by the use of capacitor bank which decrease the apparent power consumption.

4.5.2 Line Voltage Variation

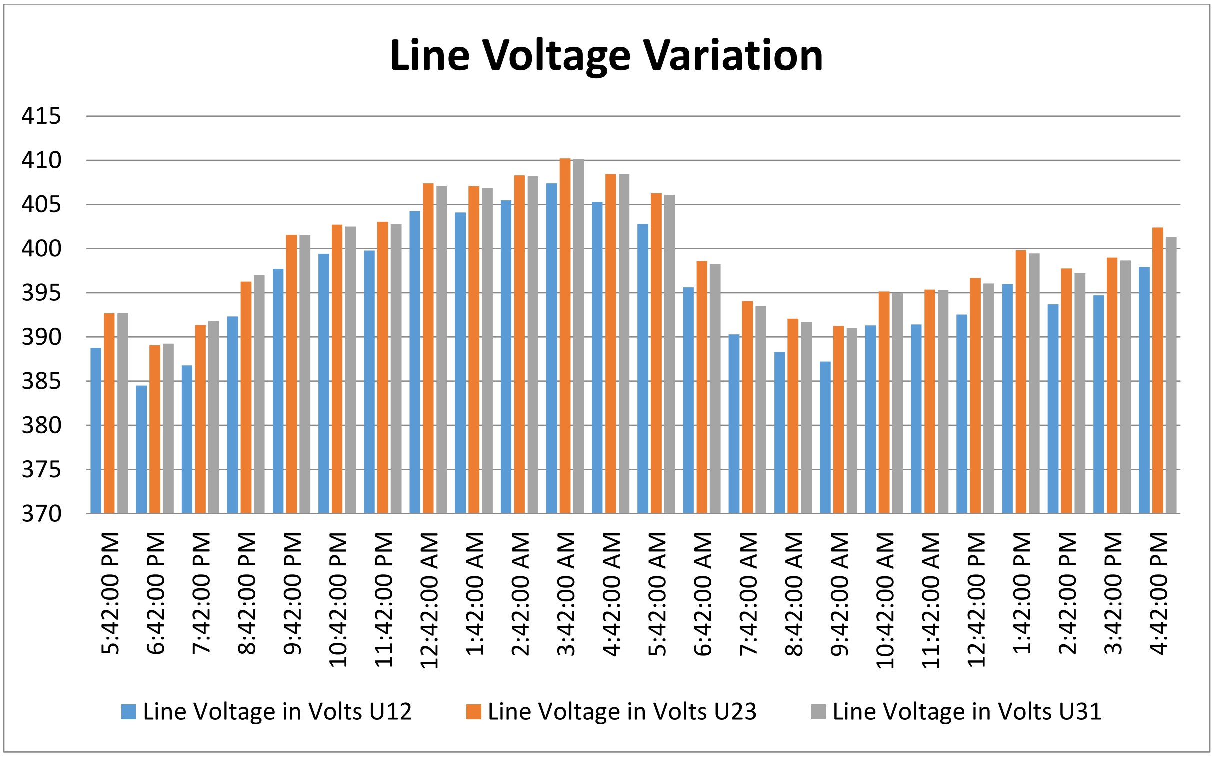

Figure 15: Line Voltage profile of 24 hr. on 8th Sept. to 9th Sept 2023.

Although the line voltage is seen varying from 384 V to 410V, the range of voltage variation is in the range of requirement. During the normal hour of the day (5AM to 5 PM), voltage is lower than 400 V required for the efficient operation of the system. The variation of the voltage is within ± 4%, which is in acceptable range.

4.5.3 Power Variation

Variation of all the three different type of power is shown in the Figure 16. Data suggests that power factor correction could enhance power usage. Utility company charge on the basis of the active power but the actual consumption is apparent power which depends upon the power factor of the system which can be corrected by the installation of the capacitor bank at the main distribution panel board or at the individual pump based on the requirement.

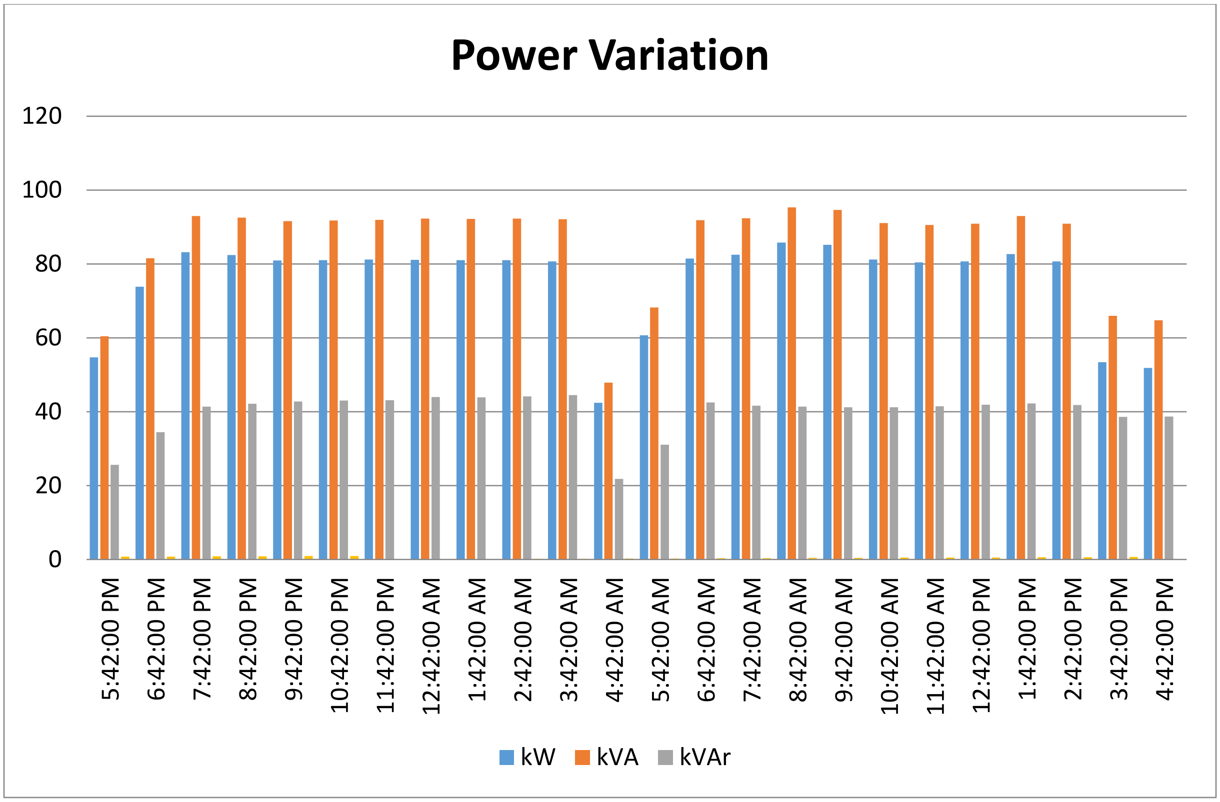

Figure 16: Active, Apparent, Reactive Power Variation

4.6 Electrical Parameter of Pumps

Electrical parameter of major pumps measured with help of three phases clamp meter. Measured data help to know the status of electrical parameter during the operation of the pumps in compared to the electrical parameters of the whole systems. Power factor of the each pump is found in same range as in the main distribution system and validate the requirement of the power factor correction.

Table 4: Electrical Parameters of Pumps measured with Three Phase Clamp Meter

S.N.	Parameters	Distribution Pump 1	Distribution Pump 2	Distribution Pump 3	Transmission Pump
1	Capacity (kW)	62	33.5	22	24.5
2	Voltage (V)	379	375	380	378.5
3	Current (A)	91.5	44.7	34.5	31.11
4	Frequency (Hz)	49.9	50	49.9	50
5	Power Factor	0.911	0.88	0.78	0.82
6	Active Power (kW)	54.5	25.5	17.8	16.33
7	Apparent Power (kVA)	60	29.04	22.53	19.84
8	Reactive Power (kVAr)	24.7	13.77	14.05	11.2

4.7 Efficiency of the System

For the pumping system to operate efficiently, it is crucial to keep an eye on its efficiency. Pumping system efficiency includes motor efficiency, coupling efficiency, pump efficiency and system efficiency. Evaluation of these parameters helps to know the present condition of the pumping system and guide to take the right measures to correct the inefficiencies in the system. Table 5 describes in details about the major operating pump with their active power, hydraulic power, system efficiency and pump efficiency considering the motor efficiency 90 percent.

Table 5: Efficiency of the System

Pumps/ Parameters	Measured Active Power (kW)	Flow [m3 /h]	Head (m)	Hydraulic Power (kW)	System Efficiency (%)	Pump Efficiency (%)
Distribution pump 1	54.5	150	65	26.57	48.75	54.17
Distribution pump 2	25.5	85	65	15.94	59.04	65.60
Distribution pump 3	17.8	60	65	11.05	59.01	66.34
Transmission Pump	16.33	40	92	10.03	61.41	68.23

The distribution pumps operate in parallel combination with the common head of 65 meter and respective flow rates. These pumps are operating under lower efficiency than the desired efficiency. The cause for the lower efficiency is due to the over/under sizing of the pump during its selection. This increases the consumption of the energy. One way to overcome this loss is to install the variable frequency drive (VFD). Other one is to avoid the over/under size pump selection. For the given case of pumps, average efficiency found as 63.58 % which is less than the best efficiency (75%) of the pump. Correct size pumps for the given system provide the required efficiency with 355.96 kWh of electrical energy daily and NRS 662623.5cost saving annually.

Transmission pump is also operating under lower efficiency and the operation with VFD is not the right solution for this case as the head required will be constant for the given requirement once the pump is installed. So the proper capacity pump selection is required. Pump selection with the hydraulic simulation of the pipe line and desired pump characteristics can be evaluated with the help of EPANET 2.2.

4.8 Pump Sizing and Pump Selection

Pump sizing means the determination of the capacity of the pump for the required application. The characteristics like static head, dynamic head, total head, pipe size, pipe materials, bend, other fittings, flow rate, velocity etc. of the applications for which the pump required play important role in pump capacity determination. Pump selection depends on the purpose for which pump will be used. Pump with constant head, constant discharge, pressure regulated head and discharge are major selection criteria. The operating data for head and discharge is the point at the intersection of the pump characteristic and the system curve.

4.9 Case Study: Determination of Pump Head and Discharge

4.9.1 Characteristics Curve of pump

At Sundarighat WTP, KSB made 24.5 kW submersible pump is used for the transmission of the water from Sundarighat reservoir to Bhajangal tank.

Characteristics of the pump are as follows:

- Nominal Discharge: 22.2 lps(1332 lpm)
- Nominal Head: 72 m
- Discharge range: (40-100) m^3/h
- Head range: 92-48 m
- Rated Speed: 2900 rpm
- Motor Rating: 24.5 kW
- Max Current: 55 A
- Rated Voltage: 415+6% to 415-15%
- Rated Frequency: 50 Hz

The characteristics curve of the above pump obtained from the suppliers verified with pump test done at the electromechanical pump test bench. The test is done in the closed loop pumping system with sluice valve control method. Plot of the characteristics curve is drawn as shown in *Figure 17*.

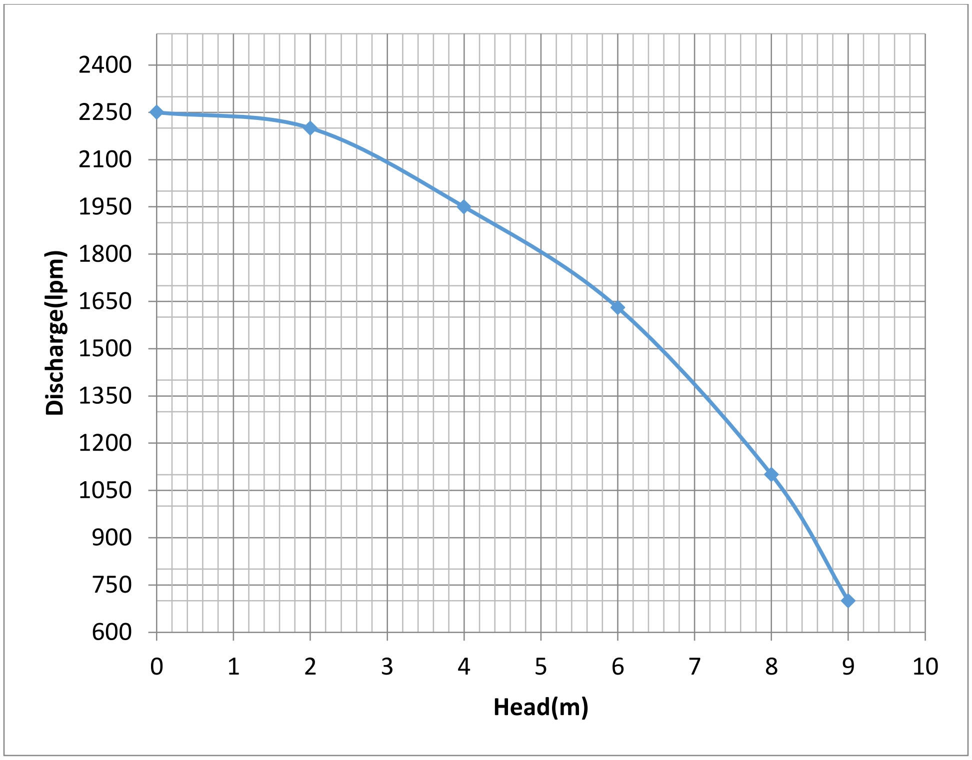

Figure 17: Pump Test Report (case study).

4.9.2 Modeling of pumping system in EPANET

The model of pumping system with pipeline and reservoir of case study is prepared using hydraulic simulation EPANET software with the help of the Google earth application as shown in the Figure 18. The integration of Google earth application with EPANET 2.2 helps to easily locate the actual pipeline layout with its elevation at the respective point.

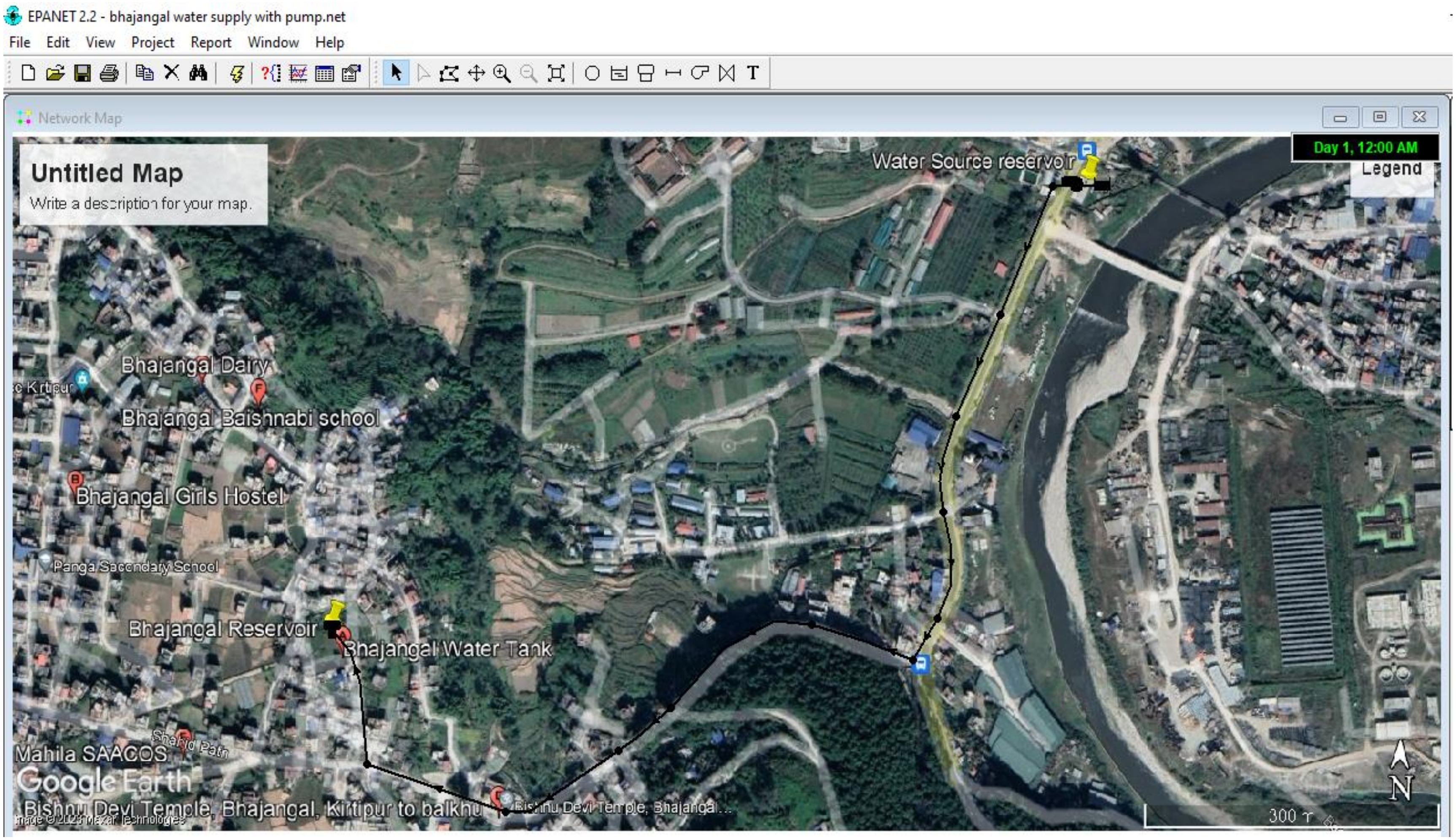

Figure 18: layout of pipeline with reservoir and tank using Google earth.

The network of pipeline with reservoir, pump, and tank of the pumping system in EPANET interface as follows.

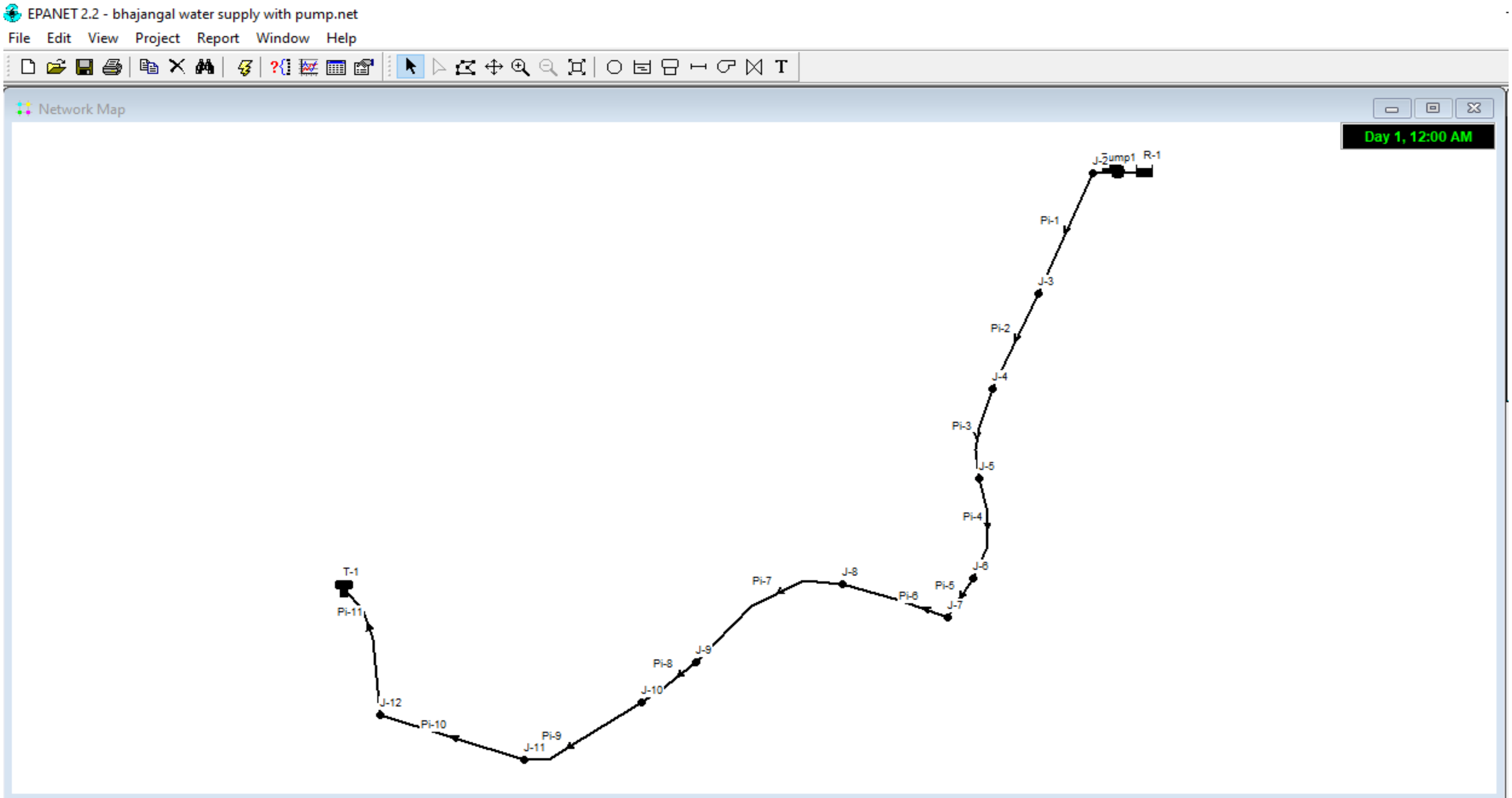

Figure 19: Pipeline Network with reservoir, pump and Tank.

4.9.3 Simulation of model based on Characteristics Curve

Simulation of the pumping system is performed considering the characteristics curve of pump at its nominal specifications that is 1332 lpm discharge at 72 meter head.

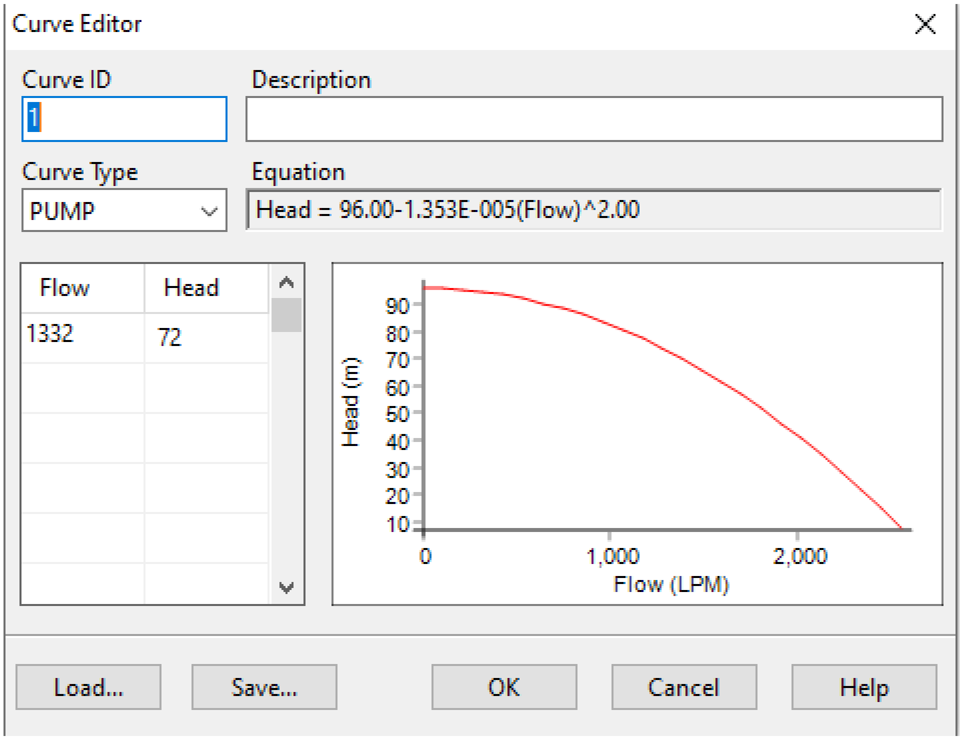

Figure 20: characteristics curve of the case study pump

The pump's characteristics curve is created by the curve editor using the nominal flow and head values that are needed as input for the simulation process. Figure 20 shows setting of the characteristics curve of the case study pump at its nominal head and discharge.

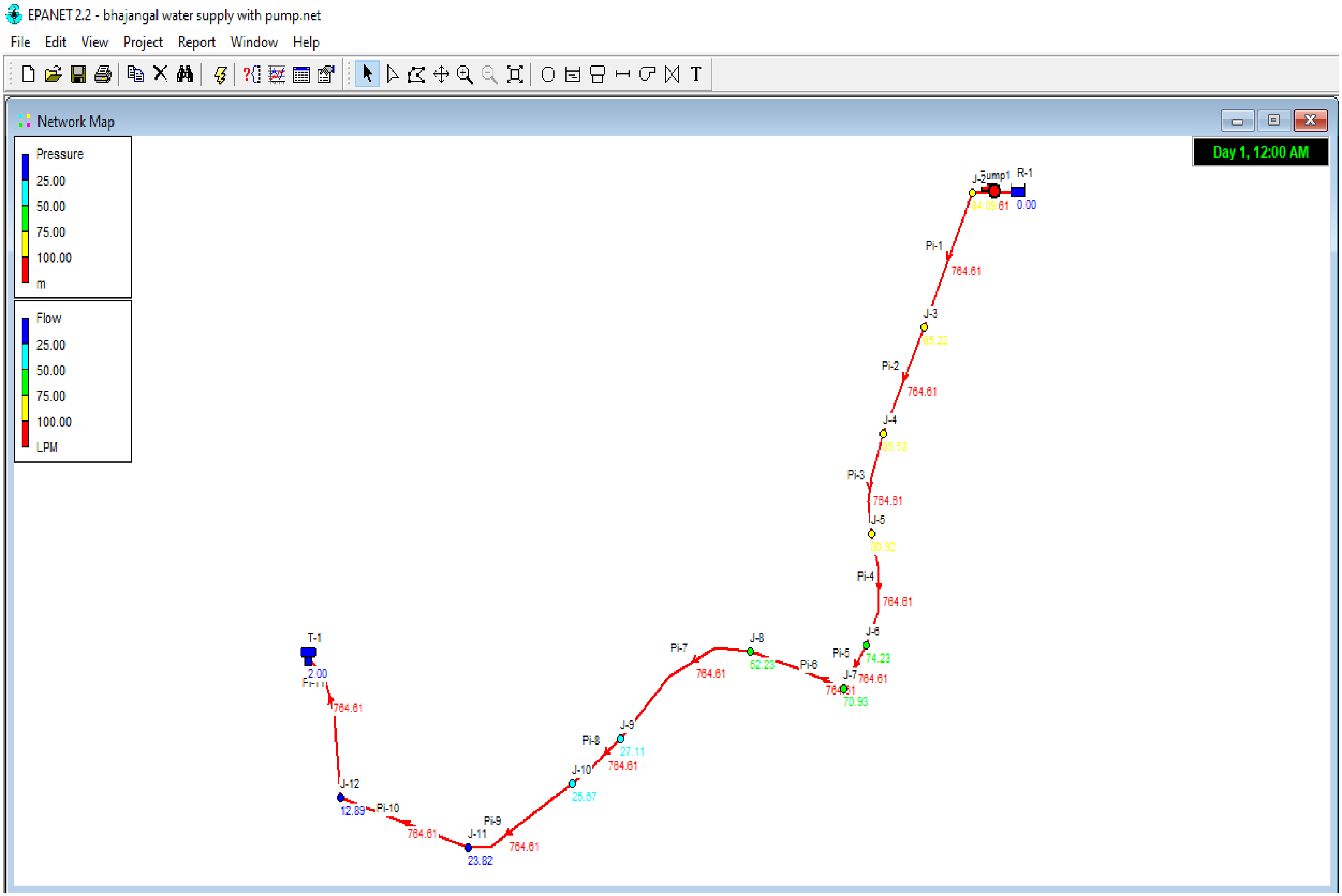

Figure 21: Simulation result with flow and pressure value at link and node

Above Figure 21shows the result of simulation. Node value represents pressure at respective node and flow through each section of pipe is same as 764.61 lpm.

Simulation results report for the energy required by the pump, network table for each node, network table for each link and pressure distribution from the EPANET presented as follows.

Table 6: Energy report

Energy Report

Table | Chart

Pump	Percent Utilization	Average Efficiency	Kw-hr /m3	Average Kwatts	Peak Kwatts	Cost /day
Pump1	100.00	75.00	0.32	14.67	14.67	0.00
Total Cost						0.00
Demand Charge						0.00

Energy report Table 6 depicts the power developed by the pump for the given condition of the flow and head.

Table 7: Simulation result for pressure at different node

Network Table - Nodes

Node ID	Elevation m	Head m	Pressure m
Junc J-2	1281	1365.09	84.09
Junc J-3	1279	1364.22	85.22
Junc J-4	1278	1363.53	85.53
Junc J-5	1282	1362.92	80.92
Junc J-6	1288	1362.23	74.23
Junc J-7	1291	1361.93	70.93
Junc J-8	1309	1361.23	52.23
Junc J-9	1333	1360.11	27.11
Junc J-10	1334	1359.67	25.67
Junc J-11	1335	1358.82	23.82
Junc J-12	1345	1357.89	12.89
Resvr R-1	1277	1277.00	0.00
Tank T-1	1355	1357.00	2.00

Table 7 shows the value of pressure at each node and maximum pressure developed is at junction 4. Pressure variation along the pipeline can be observed and this kind of result is helpful in the selection of pipe material.

Table 8: Simulation result for flow, velocity and unit head loss for pipe section

Network Table - Links

Link ID	Length m	Diameter mm	Flow LPM	Velocity m/s	Unit Headloss m/km	Status
Pipe Pi-1	129.03	150	764.61	0.72	6.73	Open
Pipe Pi-2	103.11	150	764.61	0.72	6.73	Open
Pipe Pi-3	90.53	150	764.61	0.72	6.74	Open
Pipe Pi-4	101.96	150	764.61	0.72	6.73	Open
Pipe Pi-5	45.14	150	764.61	0.72	6.74	Open
Pipe Pi-6	103.64	150	764.61	0.72	6.73	Open
Pipe Pi-7	166.77	150	764.61	0.72	6.74	Open
Pipe Pi-8	64.47	150	764.61	0.72	6.73	Open
Pipe Pi-9	126.07	150	764.61	0.72	6.73	Open
Pipe Pi-11	132.56	150	764.61	0.72	6.74	Open
Pipe Pi-10	138.30	150	764.61	0.72	6.73	Open
Pump Pump1	#N/A	#N/A	764.61	0.00	-88.09	Open

Table 8, report about the flow through pipe, velocity of flow and head loss per kilometer along the pipeline. The velocity of flow should be in the limit (up to 5m/s) to avoid unnecessary turbulence in the pipe. Velocity and unit head loss varies with the dimension of pipe and pipe materials for the given pipeline. In this case study dimension and material of pipeline are same so the respective value also can be observed 0.72m/s and 6.73m/km throughout the pipeline.

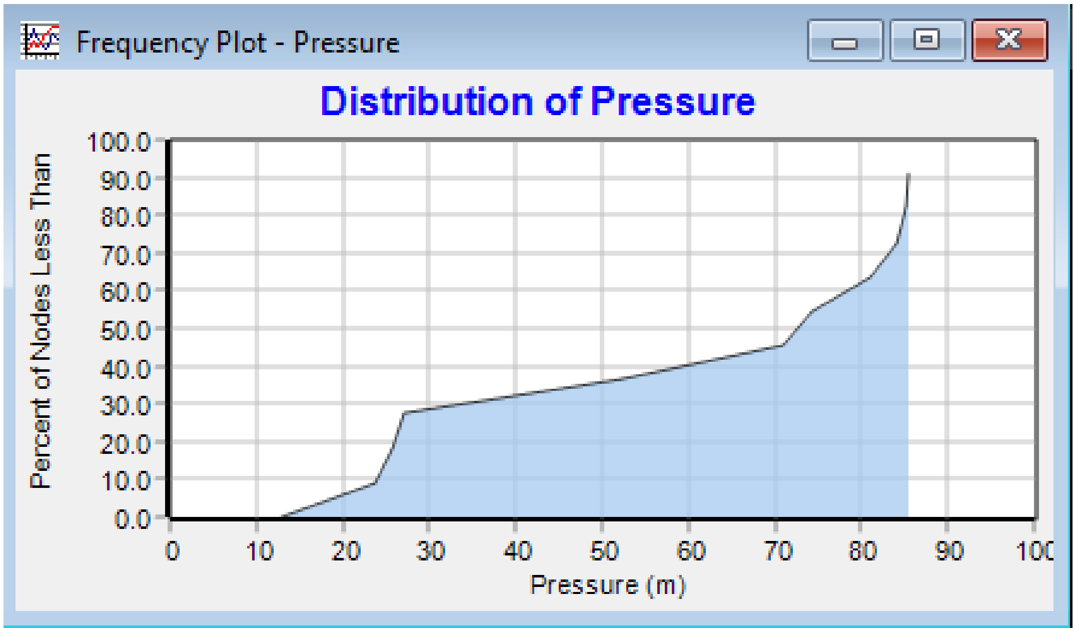

Figure 22: Pressure Variation with percentage of node.

Figure 22, shows distribution of pressure as percentage of nodes having pressure less than for the given value of pressure.

From the above simulation result it has been found that the pump used is not reliable for the pumping system of the case study. For the given pump characteristics input, pumping system develop 88.09 meter head and allow to deliver 764.61 lpm with pumping capacity required by the pump is 14.67 kW. Observation at the site shows that the given pump delivers only 667.5 lpm at head 92 meter. For the present flow range simulation result shows that pump with 86 meter head will be required. Pump capacity required will be 12.51 kW and motor with rating (12.51/0.9=13.9 ~ 14kW) slightly bigger than pump capacity can be used and capacity of pump will reduce by 10.5 kW. For the transmission purpose pump size can be easily determined with EPANET and can solve the problem of over sizing of pump with achieving the desired flow.

Table 9: Comparison of Observed and Simulation Data

System Parameters	Observation Result from Site	Simulation Result with EPANET 2.2
Head(m)	92	86
Discharge(LPM)	667.5	668.27
Motor Rating	24.5	12.51
Pump Efficiency(%)	68.23	75

For the above case to get the desired flow of around 1332 lpm, head require for the can be determine from EPANET software by varying the head of the characteristics curve of the pump required.

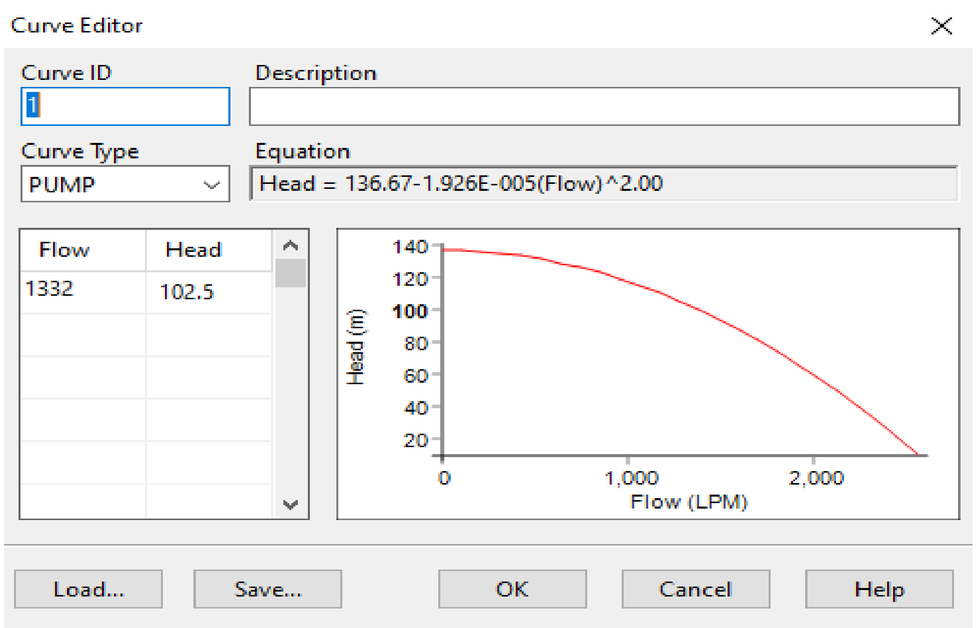

Figure 23: Characteristics curve of required pump

To get the desired flow of 1332 lpm at tank, pump with respective characteristics found by simulation with different characteristics curve.

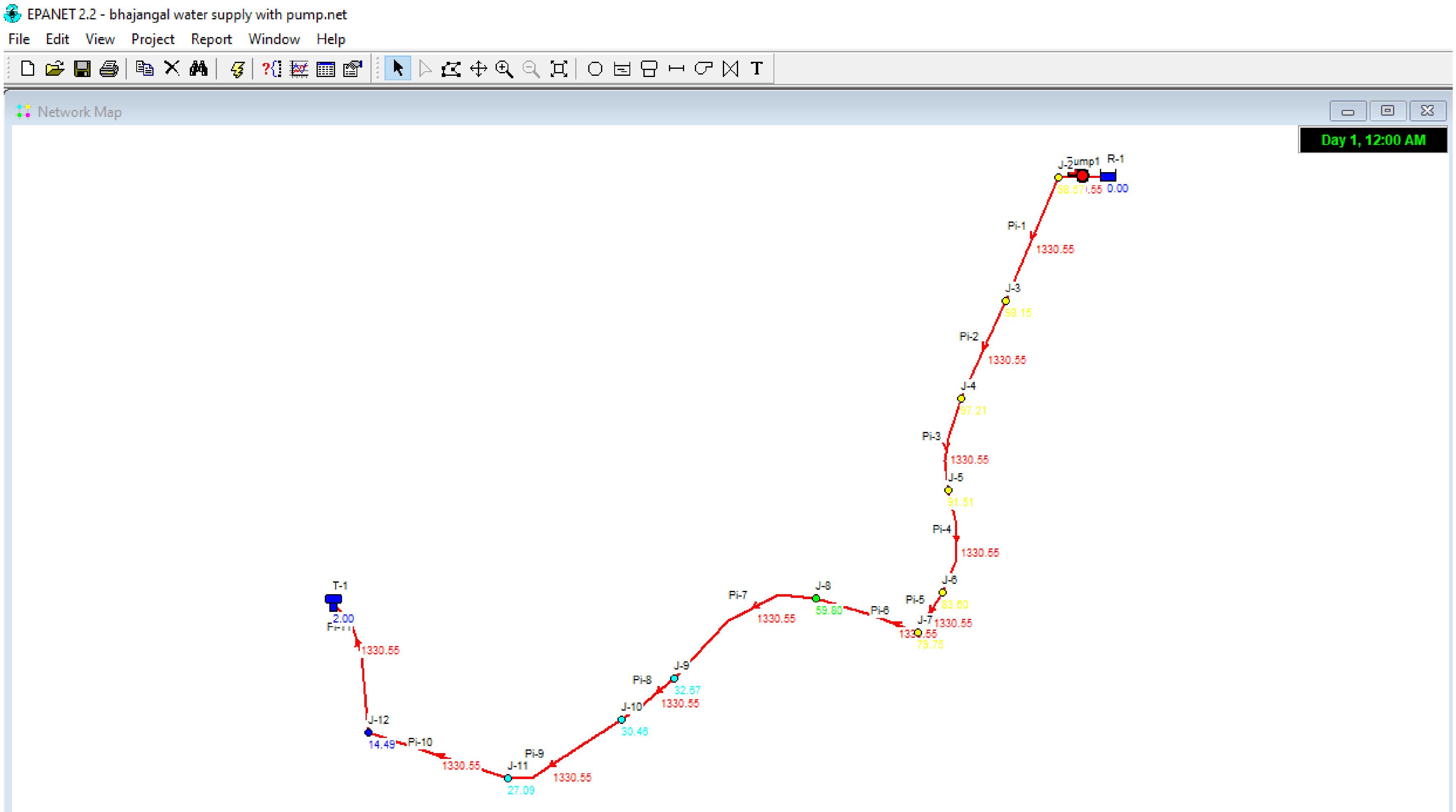

Figure 24: Simulation for the desired flow

Simulation performed for the various characteristics curve (combination of desired flow 1332 lpm and varying head value). Figure 24 show the result of simulation and nearer value of desired flow achieved at head 102.5 meter.

Table 10: Flow of water for different characteristic curve

S.N.	Head (m)	Flow(lpm)
1	90	1156.08
2	95	1232
3	100	1299.48
4	102.5	1330.55
5	103	1336.57

Table 10 shows result of desired flow for various characteristics curve input (combination of desired flow 1332 lpm and varying head value). Flow column values are the flow for the different head value in combination with desired flow of 1332 lpm.

Table 11: Result of simulation for the desired flow

Network Table - Links

Link ID	Flow LPM	Velocity m/s	Unit Headloss m/km
Pipe Pi-1	1330.55	1.25	18.79
Pipe Pi-2	1330.55	1.25	18.79
Pipe Pi-3	1330.55	1.25	18.79
Pipe Pi-4	1330.55	1.25	18.79
Pipe Pi-5	1330.55	1.25	18.79
Pipe Pi-6	1330.55	1.25	18.79
Pipe Pi-7	1330.55	1.25	18.79
Pipe Pi-8	1330.55	1.25	18.79
Pipe Pi-9	1330.55	1.25	18.79
Pipe Pi-11	1330.55	1.25	18.79
Pipe Pi-10	1330.55	1.25	18.79
Pump Pump1	1330.55	0.00	-102.57

Table 11 shows result of simulation in the tabulated form and depict the value of flow through pipe, velocity and unit headless. Hence the pump with head of 102.57 meter will deliver the desired flow of 1330.55 lpm. From the above case study EPANET software is found very useful for the determination of pump size. For this case the pump capacity required of 29.73(~30) kW. For same flow of 1332 lpm, capacity of pump required will decrease with increasing the diameter of the pipe.

4.9.4 Simulation of model based on Base Demand at Tank

In simulation with the base demand, the value of the desired flow is given as the input for the simulation. The result of simulation gives the value of required head for the given transmission pipeline. The simulation with base demand performed is shown in below.

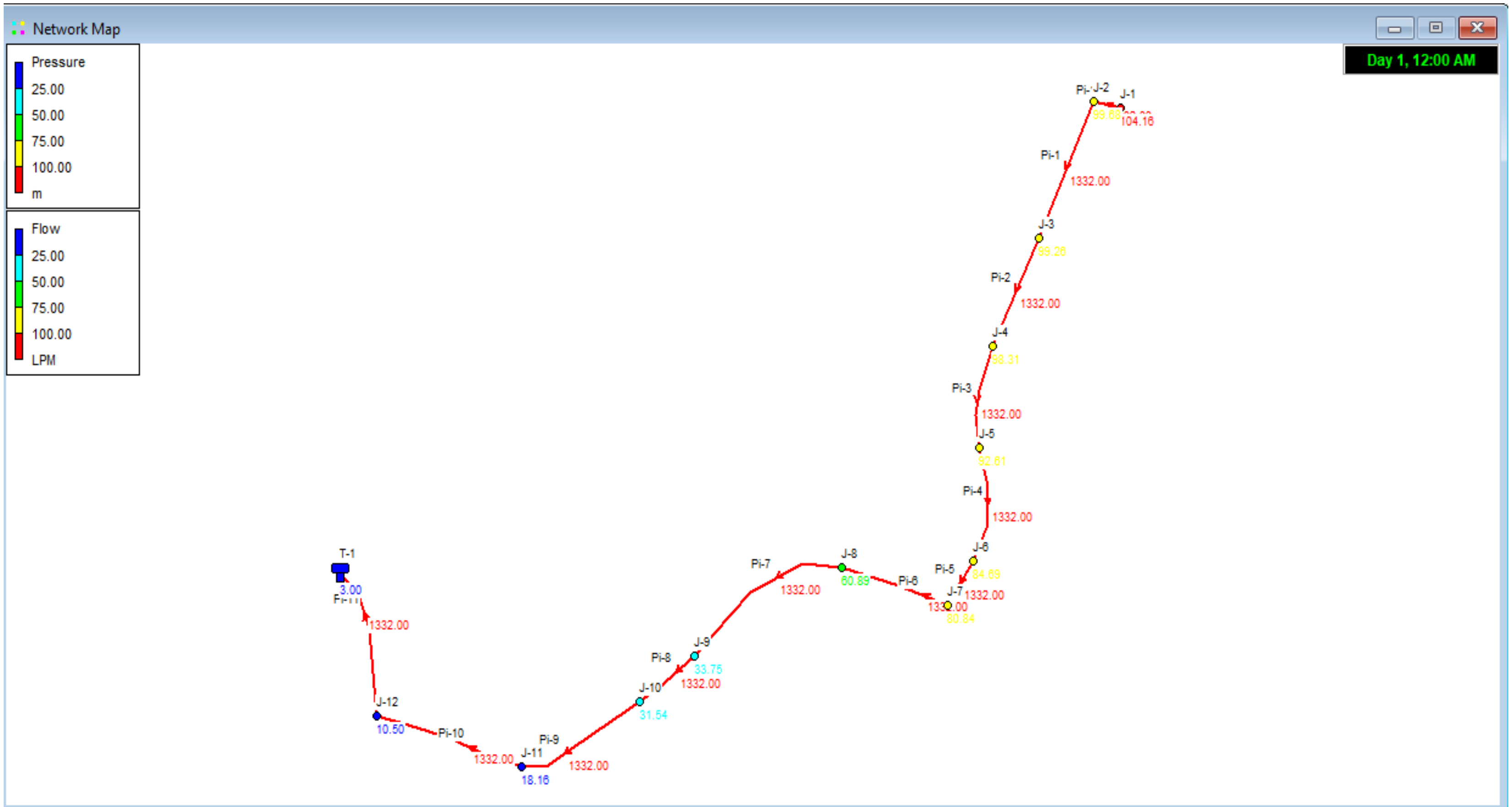

Figure 25: Simulation based on base demand

Result of simulation based on the base demand almost matches with result of simulation based on characteristics curves. Figure 25 shows the result of simulation for base demand.

Table 12: Simulation result based on base demand

Network Table - Nodes

Node ID	Elevation m	Base Demand LPM	Demand LPM	Head m	Pressure m
Junc J-1	1277	-1332	-1332.00	1381.16	104.16
Junc J-2	1281	0	0.00	1380.68	99.68
Junc J-3	1279	0	0.00	1378.26	99.26
Junc J-4	1278	0	0.00	1376.31	98.31
Junc J-5	1282	0	0.00	1374.61	92.61
Junc J-6	1288	0	0.00	1372.69	84.69
Junc J-7	1291	0	0.00	1371.84	80.84
Junc J-8	1309	0	0.00	1369.89	60.89
Junc J-9	1333	0	0.00	1366.75	33.75
Junc J-10	1334	0	0.00	1365.54	31.54
Junc J-11	1345	0	0.00	1363.16	18.16
Junc J-12	1350	0	0.00	1360.50	10.50
Tank T-1	1355	#N/A	1332.00	1358.00	3.00

Table 12 shows result of the simulation which clearly shows value of the demand fulfilled at the tank and the head required for the pump is 104.16 meter.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This investigation looked at the energy saving opportunity in water treatment plant by implementing the energy audit of the plant and correct sizing of the transmission pump. The plant operates under at an average power factor 0.88, which is varying from vary from 0.813 to 0.98. Specific Energy consumption and specific pumping cost of the plant found increasing over the years while treating and pumping the same amount (6 MLD) of water. Average specific energy consumption is 0.187 kWh per cubic meter of water and specific cost is NPR 0.95 per cubic meter of water for the year 2022 which were only 0.077 kWh per cubic meter of water and NPR 0.39 per cubic meter of water for the year 2015 respectively. The variation of the voltage is within ± 4% which is in acceptable range. For the given case of pumps, average efficiency found as 63.58 % which is less than the best efficiency (75%) of the pump. Correct size pumps for the given system provide the required efficiency with 355.96 kWh of electrical energy daily and NRS 662623.5 cost saving annually.

Hydraulic simulation of transmission network in EPANET 2.2 found that transmission pump oversized by 10.5 kW for the current operating condition with efficiency of 75%. Simulation result suggests the size of the desired pump having 1330 lpm discharge at 102.5 meter head and pump capacity 30 kW with operating efficiency of 75%.

5.2 RECOMMENDATIONS

The use of the hydraulic simulation software EPANET 2.2 for the design of the pipeline network and the capacity of the pump is recommended for the efficient operation of the system and optimum size pump selection.

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APPENDICES

Table 13: Annual energy production from solar & Consumption from NEA

S.N.	Year	Delivered energy (Kwh) to NEA	Received energy (Kwh) From NEA	Surplus Energy(kwh)
1	2015	418754	167776	250978
2	2016	557899	285927	271972
3	2017	655686	309639	346047
4	2018	592095	330340	261755
5	2019	606115	346681	259434
6	2020	539990	356039	183951
7	2021	504018	352641	151377
8	2022	567943	408535	159408

Table 14: Major connected load of Sundarighat WTP

S.N.	Major Equipment	Rating	Purpose	Operating Schedule
1	Distribution Pump 1	62 KW	Distribution to allocated Area	Continuous(Weekly avg. 18.3 hours per day)
2	Distribution Pump 2	33.5 KW	Distribution to allocated Area	Continuous(Weekly avg. 13.57 hours per day)
3	Distribution Pump 3	22 KW	Distribution to allocated Area	Continuous(Weekly avg. 9.28 hours per day)
4	Distribution Pump 4	22 KW	Distribution to allocated Area	Alternatively used for pump 3
5	Distribution Pump 5	7.5 KW	Distribution to allocated Area	Continuous(24 hours per day)

6	Backwash Pump	22 KW	Backwash for pressure filter	10-20 minutes per day
S.N.	**Major Equipment**	**Rating**	**Purpose**	**Operating Schedule**
7	Transmission Pump 1	24.5 kW	Bhajangal & Devdhoka Reservoir	4-5 hours per day
8	Tanker Filling Pump	5 kW	Tanker filling	3-4 hours per day
9	PAC & Alum Agitator 1	1.5 KW	Chmical Agitator	2-3 hours per day
10	PAC & Alum Agitator 1	1.5 KW	Chmical Agitator	Alternative to pump 1
11	PAC Dosing Pump 1	0.55KW	Chemical Dosing	2-3 hours per day
12	PAC Dosing Pump 2	0.55KW	Chemical Dosing	2-3 hours per day
13	Alum Dosing Pump 1	0.75KW	Chemical Dosing	2-3 hours per day
14	Alum Dosing Pump 2	0.75KW	Chemical Dosing	2-3 hours per day
15	Chlorine Agitator	1.5 KW	Chlorine Agitator	5-6 hours per day
16	Chlorine Dosing pump	0.5 KW	Chlorine Dosing	2 hours per day
17	Others Loads	10 kW	Electrical Appliances	As per Need

Table 15: Hourly data from power quality analyzer for phase voltage, line voltage, line current, frequency and PF

Date	Time	Phase Voltage in Volts			Line Voltage in Volts			Line Current in Amps			Freq. avg.	PF avg.
		U1N	U2N	U3N	U12	U23	U31	A1	A2	A3		
9/8/2023	5:42:00 PM	225.22	225.19	227.48	388.77	392.69	392.68	84.94	86.37	96.09	50.009	0.9055
9/8/2023	6:42:00 PM	222.78	222.99	225.59	384.51	389.07	389.25	126.02	122.59	123.81	49.979	0.9068
9/8/2023	7:42:00 PM	224.3	224.15	227.02	386.79	391.33	391.81	132.85	135.58	144.37	49.994	0.8949
9/8/2023	8:42:00 PM	227.48	227.16	229.87	392.33	396.28	397	129.8	133.8	141.96	49.999	0.89
9/8/2023	9:42:00 PM	230.24	230.42	232.62	397.73	401.55	401.5	127.87	133.09	135.38	49.966	0.8839
9/8/2023	10:42:00 PM	231.05	231.31	233.13	399.41	402.71	402.51	128.06	133.26	134.48	50.013	0.883
9/8/2023	11:42:00 PM	231.22	231.53	233.28	399.77	403.03	402.75	128.53	133.1	134.56	50.048	0.883
9/9/2023	12:42:00 AM	233.77	234.1	235.76	404.25	407.39	407.07	127.73	132.38	133.45	50.002	0.8791
9/9/2023	1:42:00 AM	233.69	233.93	235.58	404.07	407.04	406.89	127.82	131.85	133.55	50.005	0.8791
9/9/2023	2:42:00 AM	234.49	234.7	236.3	405.46	408.3	408.19	127.55	131.61	133.25	50.009	0.8781
9/9/2023	3:42:00 AM	235.63	235.8	237.4	407.39	410.19	410.14	126.51	130.79	132.67	49.952	0.8756
9/9/2023	4:42:00 AM	234.51	234.61	236.49	405.3	408.42	408.43	72.28	75.63	73.87	49.932	0.9786
9/9/2023	5:42:00 AM	233.05	233.27	235.25	402.8	406.26	406.08	95.79	103.31	100.86	49.966	0.8905
9/9/2023	6:42:00 AM	228.78	229.07	230.62	395.62	398.58	398.27	129.36	134.31	136.63	49.896	0.8863
9/9/2023	7:42:00 AM	225.75	226.2	228.05	390.29	394.04	393.48	131.11	136.94	139.58	50.018	0.8923
9/9/2023	8:42:00 AM	224.59	225.17	226.95	388.31	392.07	391.71	144.15	140.03	138.43	50.025	0.9002
9/9/2023	9:42:00 AM	224.23	224.33	226.65	387.2	391.25	391.03	130.27	141.71	148.42	50.035	0.8997
9/9/2023	10:42:00 AM	226.46	226.72	228.91	391.3	395.16	394.95	127.18	137.92	135.52	49.973	0.8912
9/9/2023	11:42:00 AM	226.62	226.79	229.05	391.4	395.37	395.29	127.5	133.72	136.7	49.969	0.8885
9/9/2023	12:42:00 PM	227.11	227.6	229.62	392.55	396.68	396.06	128.13	133.92	136.49	49.943	0.887
9/9/2023	1:42:00 PM	229.11	229.43	231.56	395.99	399.83	399.46	126.69	140.48	136.77	49.987	0.8898
9/9/2023	2:42:00 PM	227.77	228.23	230.26	393.7	397.76	397.19	127.21	134.4	135.86	49.986	0.8876
9/9/2023	3:42:00 PM	228.49	228.83	231.08	394.71	398.97	398.65	93.7	96.18	97.55	50	0.8096
9/9/2023	4:42:00 PM	230.1	230.86	232.79	397.89	402.38	401.33	91.72	92.94	95.32	49.978	0.8013

Date	Time	Phase Voltage in Volts			Line Voltage in Volts			Line Current in Amps			Freq. avg.	PF avg.
		U1N	U2N	U3N	U12	U23	U31	A1	A2	A3		
9/9/2023	5:42:00 PM	229.74	230.22	232.41	396.93	401.61	400.68	61.94	64.17	73.85	49.953	0.8856
9/9/2023	6:42:00 PM	227.36	227.68	229.93	392.82	397.05	396.52	140.68	153.25	158.97	49.997	0.8665
9/9/2023	7:42:00 PM	229.09	229.15	231.95	395.31	400.03	400.1	138.89	147.08	154.41	50.059	0.8583
9/9/2023	8:42:00 PM	231.05	231.18	233.54	399.03	403.06	403.02	138.63	147.11	151.97	50.054	0.8551
9/9/2023	9:42:00 PM	230.49	230.61	233.17	397.93	402.3	402.29	136.38	144.46	150.35	50.018	0.8526
9/9/2023	10:42:00 PM	235.05	235.16	236.85	406.27	409.24	409.17	41.95	45.83	46.19	50.016	0.863
9/9/2023	11:42:00 PM	235.57	235.55	237.26	407.09	409.84	410.01	42.88	45.59	45.76	49.98	0.8583
9/10/2023	12:42:00 AM	234.03	233.92	235.56	404.42	406.89	407.2	42.18	45.7	45.39	49.983	0.8641
9/10/2023	1:42:00 AM	236.7	236.68	238.31	409.12	411.69	411.86	42.61	46.76	45.62	49.957	0.8564
9/10/2023	2:42:00 AM	235.61	235.58	237.15	407.25	409.75	409.89	41.59	45.9	45.29	49.961	0.8593
9/10/2023	3:42:00 AM	237	236.93	238.58	409.63	412.13	412.33	29.02	32.97	31.47	49.986	0.9898
9/10/2023	4:42:00 AM	232.27	232.56	233.95	401.79	404.42	404.14	145.75	152.25	154.55	49.99	0.854
9/10/2023	5:42:00 AM	231.69	232.04	233.51	400.77	403.61	403.27	146.1	151.53	153.92	49.96	0.8545
9/10/2023	6:42:00 AM	228.51	228.75	230.35	395.19	398.01	397.79	145.39	156.03	155.24	49.995	0.864
9/10/2023	7:42:00 AM	226.01	226.47	228.23	390.92	394.26	393.85	152.47	162.07	158.13	50	0.8716
9/10/2023	8:42:00 AM	220.82	221.24	223.26	381.6	385.48	385.28	165.32	167.72	168.96	49.999	0.8782
9/10/2023	9:42:00 AM	220.66	220.91	223.13	381.13	385.2	384.96	120.18	126.88	129.87	50.066	0.8927
9/10/2023	10:42:00 AM	221.25	221.71	223.67	382.41	386.42	385.81	125.18	132.24	134.69	50.058	0.8935

Table 16: Hourly data of Active, Apparent and Reactive power data from power quality analyzer

Date	Time	Active Power in kW			kW	Apparent Power in kVA			kVA	Apparent Power in kVAr			kVAr
		P1	P2	P3		S1	S2	S3		Q1	Q2	Q3	
9/8/2023	5:42:00 PM	17.03	17.7	19.99	54.71	19.13	19.44	21.85	60.43	8.72	8.05	8.83	25.6
9/8/2023	6:42:00 PM	25.09	24.54	24.21	73.84	27.58	26.73	27.2	81.51	11.45	10.58	12.39	34.42
9/8/2023	7:42:00 PM	26.4	27.69	29.1	83.19	29.8	30.39	32.77	92.96	13.81	12.53	15.07	41.42
9/8/2023	8:42:00 PM	25.92	27.56	28.89	82.37	29.53	30.39	32.63	92.55	14.15	12.81	15.17	42.12
9/8/2023	9:42:00 PM	25.82	27.63	27.52	80.97	29.44	30.67	31.49	91.6	14.14	13.3	15.32	42.76
9/8/2023	10:42:00 PM	25.96	27.68	27.39	81.03	29.59	30.83	31.35	91.76	14.2	13.57	15.25	43.02
9/8/2023	11:42:00 PM	26.07	27.67	27.43	81.17	29.72	30.82	31.39	91.93	14.26	13.57	15.25	43.09
9/9/2023	12:42:00 AM	26.07	27.7	27.37	81.15	29.86	30.99	31.46	92.31	14.55	13.89	15.51	43.95
9/9/2023	1:42:00 AM	26.08	27.57	27.39	81.04	29.87	30.84	31.46	92.18	14.57	13.84	15.48	43.88
9/9/2023	2:42:00 AM	26.09	27.56	27.38	81.03	29.91	30.89	31.49	92.29	14.63	13.95	15.54	44.12
9/9/2023	3:42:00 AM	25.94	27.44	27.31	80.68	29.81	30.84	31.5	92.14	14.69	14.08	15.69	44.46
9/9/2023	4:42:00 AM	13.64	14.69	14.07	42.4	15.55	16.27	16.06	47.87	7.43	6.95	7.39	21.78
9/9/2023	5:42:00 AM	19.12	21.32	20.23	60.68	21.73	23.45	23.04	68.23	10.33	9.76	11.01	31.1
9/9/2023	6:42:00 AM	26.1	27.65	27.67	81.42	29.59	30.77	31.51	91.87	13.95	13.48	15.08	42.51
9/9/2023	7:42:00 AM	26.31	28.05	28.09	82.45	29.6	30.97	31.83	92.4	13.56	13.14	14.97	41.67
9/9/2023	8:42:00 AM	29.45	28.72	27.65	85.81	32.37	31.53	31.42	95.32	13.46	13.01	14.92	41.39
9/9/2023	9:42:00 AM	25.93	29.07	30.15	85.14	29.21	31.78	33.64	94.63	13.45	12.86	14.92	41.23
9/9/2023	10:42:00 AM	25.47	28.5	27.21	81.18	28.8	31.27	31.02	91.09	13.44	12.85	14.9	41.2
9/9/2023	11:42:00 AM	25.52	27.44	27.47	80.43	28.89	30.33	31.31	90.53	13.54	12.9	15.03	41.47
9/9/2023	12:42:00 PM	25.72	27.52	27.41	80.65	29.1	30.48	31.34	90.92	13.6	13.11	15.2	41.91
9/9/2023	1:42:00 PM	25.61	29.37	27.71	82.68	29.02	32.23	31.67	92.93	13.66	13.28	15.34	42.28
9/9/2023	2:42:00 PM	25.64	27.7	27.37	80.71	28.97	30.67	31.28	90.93	13.5	13.17	15.14	41.81
9/9/2023	3:42:00 PM	17.32	18.3	17.77	53.39	21.41	22	22.53	65.94	12.58	12.2	13.85	38.63
9/9/2023	4:42:00 PM	17.09	17.54	17.26	51.88	21.1	21.45	22.19	64.74	12.38	12.35	13.94	38.67

Date	Time	Active Power in kW			kW	Apparent Power in kVA			kVA	Apparent Power in kVAr			kVAr
		P1	P2	P3		S1	S2	S3		Q1	Q2	Q3	
9/9/2023	5:42:00 PM	12.31	13.18	15.39	40.88	14.23	14.77	17.16	46.16	7.14	6.67	7.58	21.39
9/9/2023	6:42:00 PM	27.24	30.99	31.4	89.62	31.98	34.89	36.55	103.43	16.77	16.04	18.71	51.51
9/9/2023	7:42:00 PM	26.87	29.78	30.32	86.97	31.82	33.7	35.81	101.33	17.04	15.78	19.05	51.87
9/9/2023	8:42:00 PM	26.97	29.89	29.95	86.81	32.03	34.01	35.48	101.52	17.29	16.22	19.02	52.53
9/9/2023	9:42:00 PM	26.37	29.28	29.44	85.09	31.43	33.31	35.05	99.79	17.11	15.89	19.01	52.01
9/9/2023	10:42:00 PM	8.44	9.6	9.2	27.25	9.86	10.78	10.94	31.58	5.09	4.89	5.91	15.9
9/9/2023	11:42:00 PM	8.54	9.54	9.12	27.21	10.1	10.74	10.86	31.7	5.4	4.92	5.89	16.2
9/10/2023	12:42:00 AM	8.43	9.54	9.04	27.01	9.87	10.69	10.69	31.25	5.14	4.82	5.71	15.67
9/10/2023	1:42:00 AM	8.49	9.83	9.1	27.42	10.08	11.06	10.87	32.02	5.44	5.08	5.94	16.46
9/10/2023	2:42:00 AM	8.34	9.59	9.01	26.94	9.8	10.81	10.74	31.35	5.14	4.99	5.85	15.98
9/10/2023	3:42:00 AM	4.04	5.62	4.35	14.02	4.77	6.28	5.21	16.25	2.53	2.15	2.85	7.53
9/10/2023	4:42:00 AM	28.71	30.82	30.49	90.02	33.85	35.41	36.16	105.42	17.94	17.43	19.43	54.8
9/10/2023	5:42:00 AM	28.67	30.68	30.33	89.68	33.85	35.16	35.94	104.95	17.99	17.17	19.28	54.45
9/10/2023	6:42:00 AM	28.41	31.55	30.47	90.43	33.22	35.69	35.75	104.66	17.21	16.68	18.7	52.6
9/10/2023	7:42:00 AM	29.83	32.74	30.78	93.35	34.41	36.65	36.04	107.1	17.14	16.48	18.75	52.37
9/10/2023	8:42:00 AM	32.14	33.24	32.36	97.74	36.49	37.1	37.71	111.3	17.28	16.46	19.36	53.11
9/10/2023	9:42:00 AM	23.48	25.4	25.44	74.32	26.43	27.94	28.88	83.25	12.14	11.62	13.68	37.44
9/10/2023	10:42:00 AM	24.7	26.62	26.54	77.86	27.7	29.32	30.13	87.14	12.53	12.28	14.26	39.06