Solar Photovoltaic Assisted Cost-efficient Brackish Water Purification System

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Abstract— **Pure drinking water is one of the major concerns all over the world as 97% of water resource is not drinkable due to high salinity. Fresh drinking water is one of the indispensable needs for human being as well as other living creatures' survival. Like many others countries in the world, Bangladesh is one of the developing countries that has not been able to overcome the freshwater crisis yet, especially for its people of the coastal regions. To assist the rural or isolated communities by fulfilling their pure drinking water demand, a small scale brackish water reverse osmosis purification system assisted by solar photovoltaic (PV) energy as the renewable energy source has been proposed in this work. It has been revealed that solar PV source serves the best for a small scale power generation for the rural or remote region and reverse osmosis process is the most economical system for brackish water purification. After a thorough experimental investigation and analysis, it was found that the system fulfilled the national and international standard of pure drinking water, where 0.19BDT/litre (0.0022USD/litre) has been achieved as the most cost-efficient outcome of the water purification system. Other existing pure drinking water systems that offers around 1.0BDT/litre (0.013USD/litre) as the retail price in Bangladesh at present.**

Keywords— Brackish water; Renewable energy; Solar PV, Desalination; RO;

I. INTRODUCTION

The world's major water source is the ocean. However, about 97% of the world's water resource is highly saline, [1] icecaps and glaciers is another 2% and remaining water is fresh water, which is 0.5% of the total water demand of the world [2]. Nowadays the shortage of drinking water is the major crisis for all nation. The situation is alarming because of the increasing freshwater demand. Third world countries like Bangladesh had badly faced this crisis because of huge populations [3]. Drinking water shortage is everywhere in Bangladesh but very crucial in coastal region. There are 19 districts in coastal regions out of 64 districts in Bangladesh [4]. There is about (60-70)% of underground coastal regions water is highly saline, which has TDS up-to 7000ppm that means the coastal regions underground water is brackish water [5]. According to the World Health Organization (WHO) the total dissolved solids (TDS) limit of salinity in water is up to 500ppm and up to 1000ppm for special cases like coastal, isolated regions [6]. Bangladesh government has taken few projects in collaboration with Japan to accomplish the drinking water demand. However, these projects are mainly designed for urban and city communities. Rural or isolated communities like the coastal people have no access to those facilities. Most of the communities couldn't use their basic rights as about 80% total population live in rural areas and fresh water is a fundamental need for them.

There are many water purification systems available all over the world such as multi-stage flashing (MSF), Multi-effect distillation (MED), Membrane distillation (MD) and reverse osmosis [7]. The proposed system is mainly designed for rural and coastal regions in Bangladesh. Reverse osmosis water purification system is the best choice for low cost water purification. Moreover, the other purification systems are expensive and difficult to maintain as compared to reverse osmosis water purification system.

To establish a reverse osmosis brackish water purification system, the major requirements is electricity because of 5-10kWh electricity will be needed for $1m^3$ reverse osmosis brackish water purification system. Electricity is one the major crisis in Bangladesh. Nowadays, total electricity generation in Bangladesh is 9500MW [8] after 5 years it would be 15000MW [9]. However, the beneficiaries of those projects are again urban communities and coastal people might not be covered. So renewable energy is the sole choice for alternative power generation for rural or coastal communities. According to the geographical location of Bangladesh, solar photovoltaic (PV) system is the best option for fulfilling the requirement of electricity demand for brackish water reverse osmosis purification system. The sunshine hour in Bangladesh is about 6-8 hours in different seasons [10] and average solar radiation is about $4.5kWh/m^2/day$ [11], which is well enough for the system along with evening lighting loads.

In this paper, a brackish water reverse osmosis purification system using renewable energy (PV system) for rural or coastal region of Bangladesh to fulfil their pure drinking water has been investigated and a prototype has developed. The experimental analysis has been done in laboratory and complete evaluation of all the parameter such as performance analysis of RO-membrane, water quality and purification standard has been executed in comparison with the national and international pure drinking water standard like WHO, ECR-97 Bangladesh and potable drinking water companies.

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II. System Methodology

To establish the brackish water purification system by reverse osmosis process using renewable energy (PV system) for rural and coastal communities. Fig. 1 shows the block diagram of the BWRO system. Firstly, collection of various samples of coastal underground brackish water for input of the proposed system. There is 3 pre-carbon filters which remove different dust, ash, iron etc. The water goes to RO membrane which is the main purifier of the system. It was found that the system had recovered the highest 70% of fresh water [12]. Then post-carbon filter is used for improving the taste of water. Then fresh drinking water can be storage for use in a tank

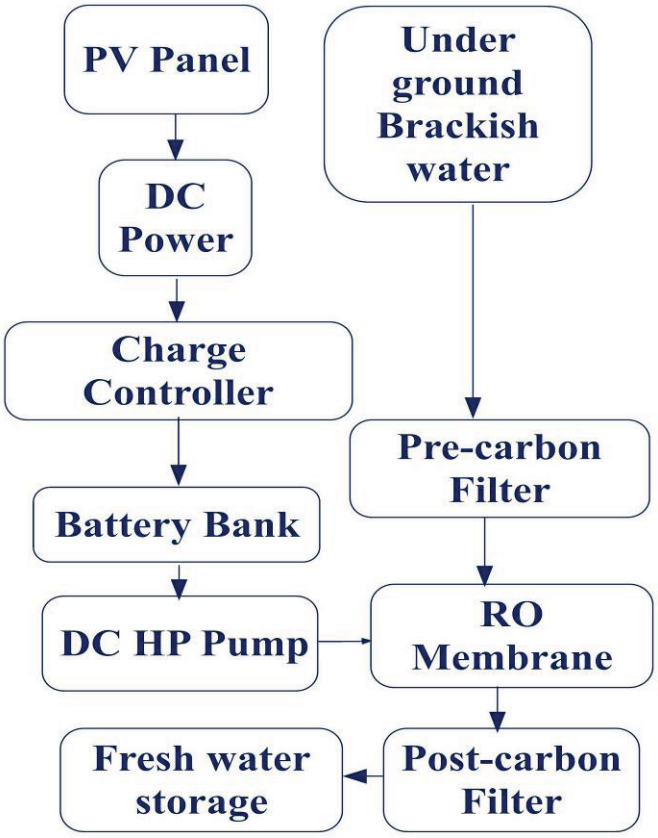

Fig. 1 Block diagram of the BWRO system

To operate the system, the major requirement is electricity. Photovoltaic (PV) system is used for fulfilling the requirement of energy demand for the brackish water reverse osmosis (BWRO) system. Electricity is the basic need to operate the HP-pump. The photovoltaic system produces DC current which will be stored into the battery through a charge controller. The system is completely DC system, so the required high pressure (HP) pump is also DC.

III. Experimental Model of the System

The proposed system consists of two parts. There are a power supply unit and brackish water reverse osmosis (BWRO) purification unit. The power supply system consists of renewable source like solar photovoltaic system, charge controller, battery, electrical load in DC. The components specification is shown in Table 1. For experimental setup requirement is 130Wp PV panel and 72W DC HP-pump and $2m^2$ RO membrane. In this setup, the system will produce 10litre of water per hour and the operating time of the system is 5hour/day [12].

TABLE 1. EXPERIMENTAL SYSTEM COMPNENETS SPECIFICAITON

Components	Capacity	Quantity	Total
PV Panel	65W	2	130W
Battery	12V, 50Ah	2	1.2KVA
Charge Controller	24V, 10Ah	1	1
HP Pump (DC)	24V, 72W	1	72W
RO membrane	$2m^2$	1	$2m^2$
Pre & post Filter	-----	4	4
Storage Tank	15litre	1	1

Fig 2 Experimental setup of the prototype

The brackish water reverse osmosis purification unit consists of a high-pressure pump, 3 pre-treatment filter and a post-treatment filter, a reverse osmosis membrane, whereby 3 tanks used as input, drain and output storage. The experimental system is installed in the Institute Energy Technology laboratory of Chittagong University of Engineering Technology (CUET), Bangladesh that is shown in Fig 2.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

According to WHO drinking water's total dissolved solids (TDS) limit is up to 500ppm and in special cases which can be up to 1000ppm [13]. However, Bangladesh government drinking water limit is about 1000ppm [14]. Underground brackish water from four (4) coastal areas in Bangladesh were collected, which are located in between Halishahar to Patenga area of Chittagong in Bangladesh. Then, the following tests are executed to find out the certain parameters of the brackish water at the environmental laboratory in the Civil Engineering department of (CUET), Bangladesh before sending to the purification system.

- Total dissolved solid
- Conductivity
- P^H
- Arsenic

After completing all of the tests if the input water, it was found that the water TDS range was 1100ppm to 7200ppm which was in brackish level. There was no arsenic in those samples, the P^H limit was 6.3-6.7 and the conductivity limits were 2.4 to 12ms that are shown in Table 2.

TABLE 2. UNDERGROUND TUBEWELL WATER INPUT SAMPLES

Item	Sample 1 Halishahar RA	Sample 2 Bandar Beach	Sample 3 Halishahar Beach	Sample 4 Patenga Beach
Total Dissolved Solids (TDS)	1100ppm	1900ppm	4200ppm	7200ppm
Conductivity	2.430ms	3.96ms	6.94ms	12.00ms
P^H	6.3	6.7	6.7	6.7
Arsenic	Nil	Nil	Nil	Nil

The standard of the P^H is 6.5 to 8.5 (by WHO), the conductivity standard is 0.1ms to 1.5ms (by WHO) and 0.1 to 2ms (in Bangladesh). After purifying all of the samples of collected brackish water by the prototype system, pure water has been collected for further investigation. The purified water samples are tested again by the environmental laboratory and the evaluated parameters of the purified water have been identified as shown in Table 3.

TABLE 3. PURIFIED WATER OUTPUT SAMPLES

Item	Sample 1 Halishahar RA	Sample 2 Bandar Beach	Sample 3 Halishahar Beach	Sample 4 Patenga Beach
Total Dissolved Solids (TDS)	100ppm	100ppm	100ppm	100ppm
Conductivity	0.3ms	0.34ms	0.4ms	0.37ms
P^H	7.9	7.6	6.8	7.2
Arsenic	Nil	Nil	Nil	Nil

According to the experimental results, it can be seen that the system purified water TDS limit to a value of 100ppm, which satisfies all of the standard as required nationally and internationally. Moreover, it also satisfied the potable drinking water standard, where TDS limit is up-to 500ppm [15] and the system recovered 40% of water, although it showed in simulation as 70% which leaves a challenge for future works.

V. COST OF THE EXPERIMENTAL SYSTEM

The cost of the experimental system is initially high which is 39,500BDT and shown in Table 4. However, the system is designed for 25 years.

TABLE 4. COST OF THE EXPERIMENTAL SYSTEM

Components	Capacity	Cost
PV Panel	130W	7,000BDT
Battery	12V, 50Ah	12,000BDT
Charge Controller	24V, 10Ah	3,000BDT
HP Pump (DC)	24V, 72W	5,000BDT
RO membrane	$2m^2$	5,000BDT
Pre & post Filter	4	4000BDT
Storage Tank	15 litre	1,500BDT
Wire, Panel and Battery support, Others	-----	2,000BDT
Total		39,500BDT

In every 5 years, the battery needs to be replaced and charge controller needs to be replaced in 10-15 years, whereas the pre and post carbon filter needs replacement in 3-6 months and RO membrane needs replacement in 18-24 months. The total production of the drinking water system is 10litre/hr and the overall cost of water purification is 0.19BDT/litre [12] without profit and bottle cost. The existing drinking water cost in Bangladesh is around 1BDT/litre without bottle cost and profit. Therefore, it is much convincing that the developed pure drinking water system is quite economical not only for coastal regions but also for regular urban usage in Bangladesh.

VI. CONCLUSIONS

This research has executed an experimental investigation on brackish water purification system using reverse osmosis process for coastal region in Bangladesh. The renewable energy mainly solar photovoltaic system has been used to purify underground brackish water. The main target of the experiment was to find out the system efficiency, components lifetime, costs and water quality. An efficient brackish water purification system has been developed for coastal regions in Bangladesh, which will help to fulfil the demand of fresh water in Bangladesh. In this work, it has been clearly found that the underground water of coastal areas in Bangladesh is brackish water, where the total dissolved solids is up to 7500ppm. After completing the reverse osmosis water purification by RO membrane, total dissolved solid reduces up to 100ppm that achieves the fresh drinking water standard set all over the world. The system is mainly designed for non-conventional energy systems, which runs on direct current (DC) system, however the system can also run on the existing conventional energy systems of Bangladesh by the changing the DC HP-Pump to AC HP-Pump using a converter. The cost of the drinkable water is found to be 0.19BDT/litre (0.0022 USD/litre), which is very cost-efficient than other existing pure drinking water systems (around 1BDT/litre or 0.013 USD/litre) in Bangladesh.

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