A Case Study on Cost-efficient Solar Powered Drinking Water System for Isolated Communities

K. M. Kabir[1,3,*], M. A. Matin[2,3], H. Misran[4] and N. Amin[4]

[1]Institute of Energy Technology, Chittagong University of Engineering & Technology, Chittagong-4349, Bangladesh
[2]Department of Electrical & Electronic Engineering, Chittagong University of Engineering & Technology, Chittagong-4349, Bangladesh
[3]Renewable Energy Laboratory (REL), Chittagong University of Engineering & Technology, Chittagong-4349, Bangladesh
[4]Institute of Sustainable Energy (ISE), Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia

[1,3,*]kazimeharajul_kabir@yahoo.com, [2,3] mamatin@cuet.ac.bd, [4]nowshad@uniten.edu.my

Abstract— **Lack of fresh drinking water in isolated communities is one of the common problems around the world. The availability of pure drinking water is only 0.5% of total freshwater demand. The fresh drinking water situation in Bangladesh is alarming especially in isolated regions. Most of the isolated and rural regions are using underground water for drinking and cooking. However, the majority of the underground water TDS level is as high as 2000-7000 mg/l, which is really harmful to human health as allowable limit is 1000 mg/l. To address this issue, a small pure drinking water system is proposed that uses available solar energy. The system is designed with reverse osmosis process for rural or isolated communities to facility he pure drinking water demand in the regions. The renowned island Sandwip has been chosen to implement the system as it is one the isolated region's in Bangladesh. It was that the water purification cost of the scheme becomes as low as $0.002/litre, which is cost-effective than present existing pure drinking water system in Bangladesh. The cost of electricity found to be as low as $0.13/kWh for evening lighting.**

***Keywords*— *Saline water; Solar PV; Desalination; RO;* cost-effective;**

I. INTRODUCTION

About 97% of the world's water is highly saline water [1] and only 0.5% of the total global water is fresh drinking water. Pure drinking water crisis is one of the major crisis in Bangladesh, whereas it is in a very alarming condition for coastal and isolated regions. About 45 million people are living in those coastal and isolated regions. [2]. Majority of the people in those areas drink underground water using tube-well, which has TDS around 2000 to 5000 mg/l making the under-ground water brackish saline water [1]. According to the World Health Organization (WHO), the total dissolved solids (TDS) limit is up-to 500 mg/l for drinking water and for special cases like coastal, isolated regions it may be allowed up-to 1000mg/l [2]. To overcome the pure drinking water crisis, several options are available all around the world such as Membrane distillation (MD), Multi-stage flashing (MSF), reverse osmosis and Multi-effect distillation (MED) [3].

Electricity and pure drinking water are very crucial basic requirements for a human. Many countries are suffering from the shortage of natural fresh drinking water along with electricity for their remote regions. Increasing amounts of fresh water demand will be required in future because of rising of populations and enhanced living standards in everywhere. Developing countries like Bangladesh is facing this situation. On the other hand, the present power generation situation in Bangladesh is not sustainable, about 80% of total population access electricity [4]. But most of those populations are urban peoples, however rural or isolated peoples didn't access those facilities. Nowadays, the total power generation in Bangladesh approximately 11,143MW [5] which is not sufficient to fulfil the total demand. On the other hand, most of the power generation stations are based on fossil fuel [6] which are going to be diminished soon. So, Renewable energy, especially the solar energy is the best solution for the new electricity requirement.

Solar PV, Wind, biomass, biogas, hydro is suitable for alternative energy. Solar PV is the most potential system for Bangladesh because of the sunshine hours is about 6-8 hours and solar radiation is approximately 4.67kWh/m^2/day in almost all areas in Bangladesh [7]. The reverse osmosis purification system is the low cost, efficient system for water purification. On the other hand, other systems are expensive and difficult to maintain than reverse osmosis system [8].

In this work, a pure drinking water system is proposed using solar energy which helps to fulfil the pure drinking water requirement in isolated or rural region in anywhere in Bangladesh. The Sandwip Island was chosen for the case study.

II. PROPOSED PURE DRINKING WATER SYSTEM

A small pure drinking water system has been proposed that includes a few parts. The details are discussed in the following subsection.

A. *Proposed System*

To establish a pure drinking water system, Reverse osmosis process is the most efficient system for isolated or rural communities. Electricity is the prime requirement to operate the system. Moreover, solar PV system is the most convenient system for isolated regions power generations.

TABLE 1. SYSTEM COMPONENT SPECIFICATION

Items	Capacity
PV Panel	400Wp
Battery	2kAh
Charge Controller	500W
HP Pump (DC)	125W
RO Membrane	1
Pre-treatment filter	3
Post- treatment filter	2
Storage Tank	200litre

978-1-5386-5229-9/18/$31.00@2018 IEEE

The proposed system consists of Solar panel, Battery bank, charge controller, high pressure (HP) pump, 3 pre-carbon filter, RO membrane, 2 post-carbon filter and a storage of pure drinking water in which is represented in Table 1. Fig. 1 shows the system block diagram.

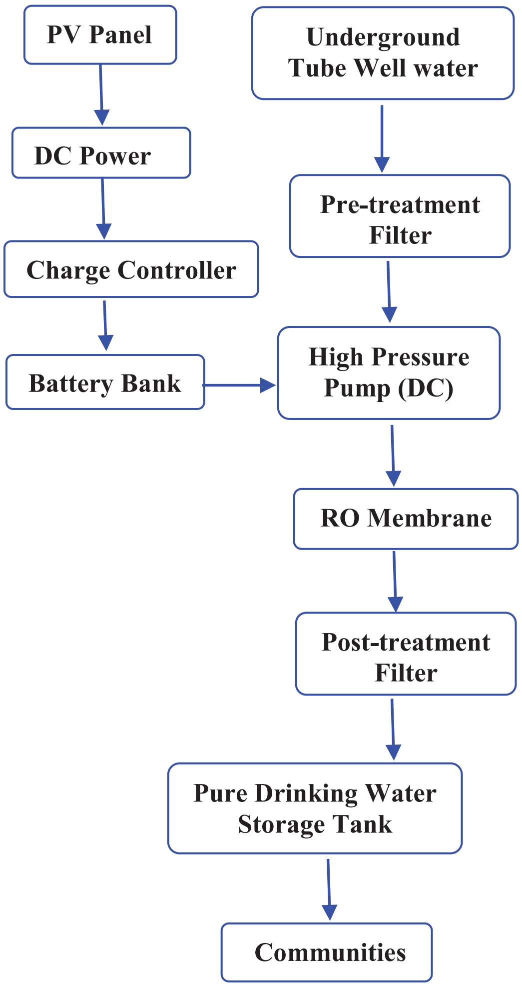

Fig. 1 Block diagram of the pure drinking water system.

B. *Proposed Water Demand Profile*

At the initial stage, Twenty (20) families selected for designing the system. All family has five (5) members in averages. Therefore, the system is mainly for 100 persons. World health organization (WHO) told that a person required 2 litre water in a day for drinking [3]. Therefore, the projected demand will be 200litre of water per day. The proposed system is produced 20 litre per hour. The operational time of the system is 10hr per day. In the proposed system, the require HP pump power is 125W_p and the operating time is 10 hours/day. So, daily electricity demand is 1.3kW/day which will briefly discussed in Section IV.

C. *Site Selection for the Study*

Sandwip is one of the isolated islands in Bangladesh which is totally isolated from the mainstream, however, belongs to Chittagong district [9]. It is located at a coastal area of Bangladesh being in 22.28' 04" north latitude and 91.27' 22" east longitude [10]. Fig. 2 illustrates the proposed location of Sandwip. The communities of this island have not access to electricity, pure drinking water and other basic amenities.

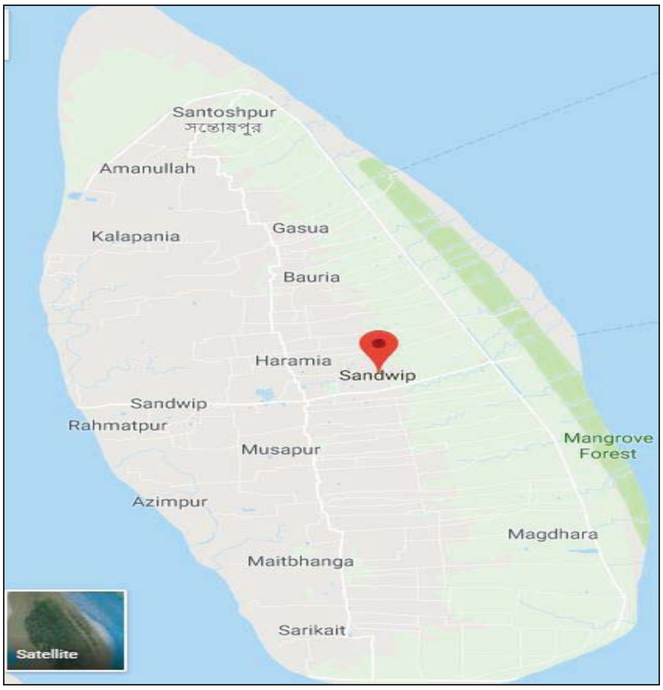

Fig. 2 Proposed location in sandwip

III. Simulation & Optimization of the System

For design, simulation, optimization and calculation, two software have been used. These are *HOMER* for solar PV system and Cost calculation and the other one is *Toray* for RO purification system optimization [11-12].

A. Reverse Osmosis purification System Design

The reverse osmosis process is the most common and cost-efficient process for saline water purification because it can recover approximately 30-70% saline-water [13]. The proposed region's water (TDS) is 3887mg/l. The initial simulation parameters of RO system present in Table 2. which may recover 60% of input water.

TABLE 2. RO PURIFICATION SYSTEM INPUT SPECIFICATION

Supply Water	33.34litre/hr
TDS	3887mg/l
Temperature	25°C
Recovery Rate	60%
P^H	6.5-8.5

A. *Solar PV System Design*

Solar energy is the most economical and alternative electricity generation system for remote or isolated communities. Solar panel converts sunlight into electricity as a direct current power and the power is stored in battery as a supplementary source. The electricity will be mainly used to fulfil the requirement of electricity for underground tube-wall water purification. The proposed PV system model and system specification are represented in Fig. 3 and in Table 3.

TABLE 3. PV CELL SPECIFICATION

Solar Panel	$0.4kW_p$
Panel Lifetime	25 years
De-rating factor	80%
Slope	23°
Ground reflectance	20.0%

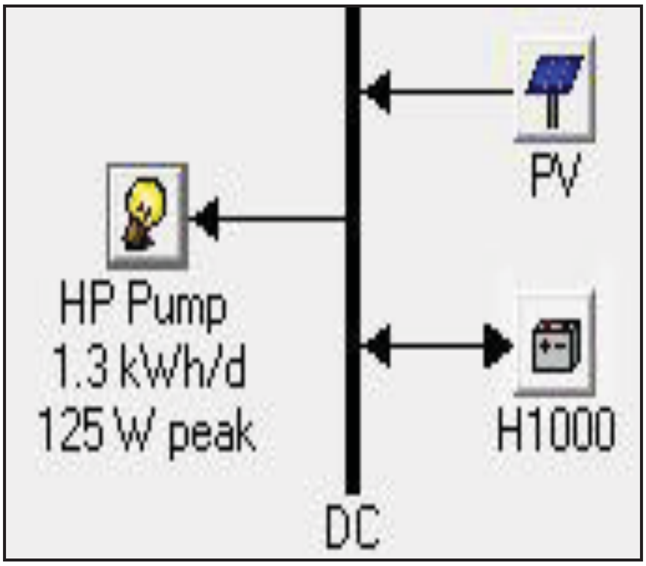

Fig. 3 Solar PV system model

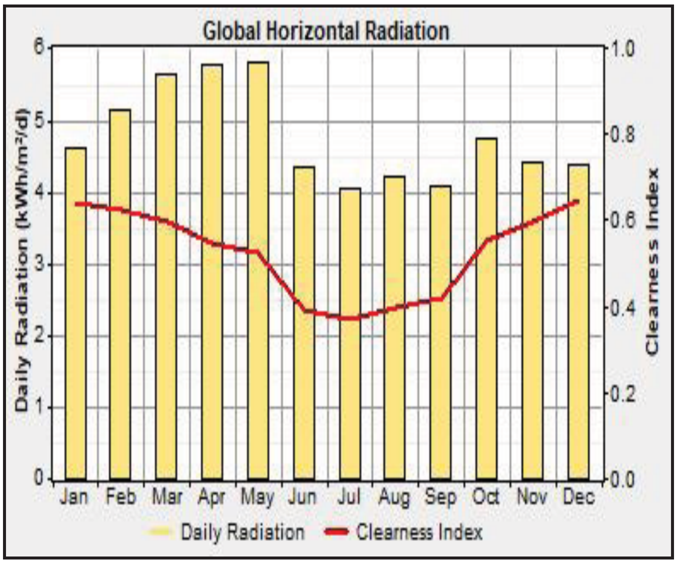

Fig. 4 Solar radiation by NASA for Sandwip

According to NASA's reports, the monthly average solar radiation in Sandwip is about $4.76kWh/m^2/day$ and average clearness index is 0.510 [14] which showed in Fig. 4

IV. RESULTS AND DISCUSSIONS OF THE SYSTEM

The section has two subsections such as RO purification system and solar system output subsection.

A. *RO Purification System Output*

The projected target of the system is to produce 20L/hr fresh drinking water and total 200L water in a day. After simulating and optimizing all the parameters, the purified water has TDS of 233mg/l which comply WHO and Bangladesh drinking water standard [3, 15]. It has been found that pump size is 0.125kW with total power consumption of $5.8kWh/m^3$. Fig. 5 and Table 4 shown the system flow diagram and output water quality respectively.

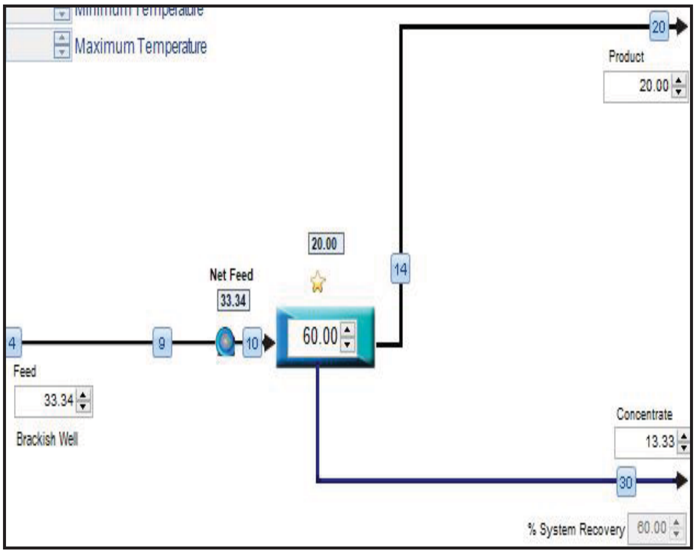

Fig. 5 RO purification system flow diagram

TABLE 4. RO PURIFICATION SYSTEM RESULT

Raw water	33.34L/hr
Target water	20L/hr
Concentrate water	13.33L/hr
Raw water TDS	3887mg/l
Fresh water TDS	233mg/l
Concentrate water TDS	11935.80mg/l
Required HP Pump (DC)	0.125kW
Total Pump Consumption	$5.8kWh/m^3$

A. *Solar System Output*

It was fund that the required high pressure (HP) pump size is 0.125kW and the operation time of the system is about 10 hours/day. After details calculation, it was found that $400W_p$ solar panel is needed to operate the system properly. The mean electricity production of the system is 1.65kWh/day and total electricity production is 602kWh/year which is represented in Fig. 6 and Table 5. The system has satisfied the power requirement of the system which is 1.3kWh/day

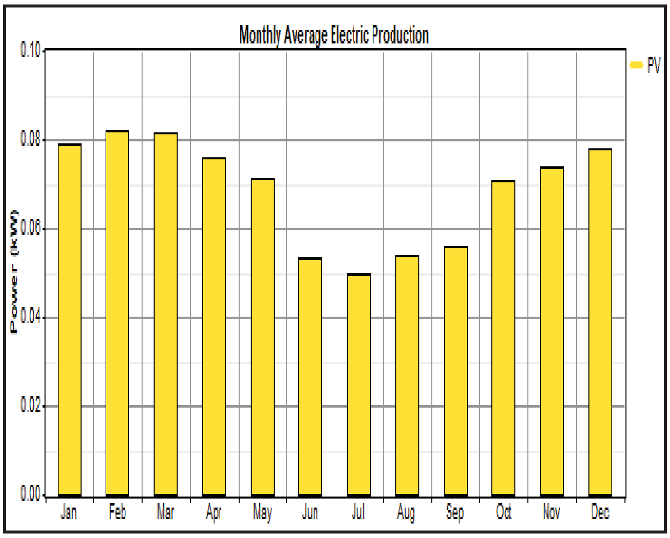

Fig. 6 Monthly electricity production from PV system

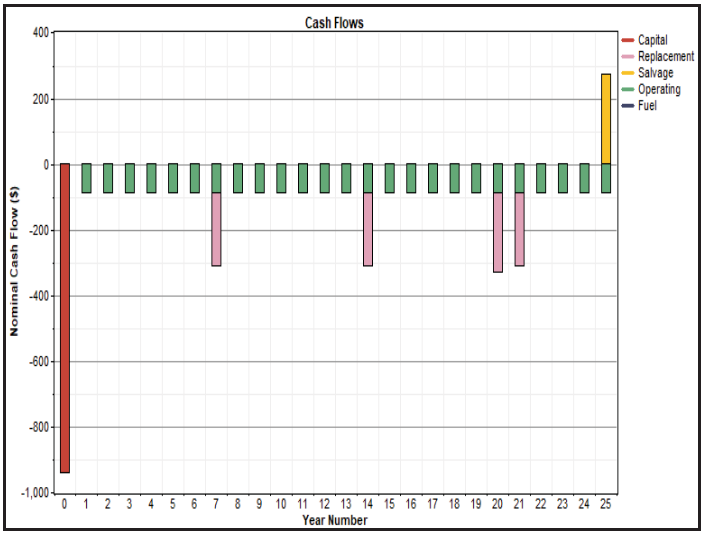

Fig. 7 Cost analysis for 25 years

TABLE 5. SOLAR POWER OUTPUT

PV Panel capacity	0.4kW$_p$
Average Electricity	0.07kW
Mean Electricity	1.65kWh/d
Capacity factor	17.4%
Total Electricity	602kWh/yr
Electricity Consumption	474kWh/yr
Excess Electricity	95.7kWh/yr
Total operation Hours	4372hrs/yr
Levelized cost	0.05$/kWh

B. *Cost Analysis of the System*

The initial cost (capital cost) of the system is high compared to present existing water purification system. However, the initial cost is $940 for 25 years and the replacement cost of the system is about $1183 (app.). Every 5 years, the battery will be replaced and RO Membrane needs replacement in 18-24 months duration. Moreover, the pre and post-treatment filters need replacement in 3-6 months. The total cost of the system is $2384 and unit cost of energy and water details are shown in Table 6 and 7 and in Fig. 7. The total maintenance cost of the system is $7.8/yr. and the cost of water is $2.06/m^3, which is much cheaper than the other counterparts [16].

TABLE 6. TOTAL COST OF THE SYSTEM [17]

Items	Capital	Replacement	Maintenance
PV Panel	$280	$75	$50
Battery	$260	$308	$50
Charge Controller	$40	$00	$00
Pump	$100	$00	$00
RO Membrane & filters	$240	$800	$95
Water Storage Tank	$20	$00	$00
Total	$940	$1183	$195

The electricity cost of the system is $0.13/kWh (or 10.4BDT/kWh) which is cost-effective than quick rental power (HFO) plants (around $0.33/kWh or 26.57BDT/kWh), Wind power plant (around 70BDT/kWh or $0.88/kWh) and Diesel power plants (around $0.39/kWh or 31.03BDT/kWh) in Bangladesh according to the latest Bangladesh power development board annual reports in 2016-17 [18].

TABLE 7. OVERALL SYSTEM SUMMARY

Net Presents Cost	$2384
Levelized Cost of Electricity	$0.13/kWh
Levelized Cost of Fresh Water	$2.06/m^3
Operating Cost of the System	$7.8/yr

V. Conclusions

In this work, investigation of the underground water purification system that uses reverse osmosis process with the help of solar photovoltaic energy for isolated communities in Bangladesh has been executed upon optimization in both HOMER and Toray Software. The main target of this work is to bring out a cost-efficient system for fulfilling the isolated communities pure drinking water demand. It has been clearly identified that most of the coastal and isolated region's underground water in Bangladesh is brackish, which has 2000 up-to 5000mg/l salinity. The predicted water has 233mg/l salinity that fulfils the national and international (WHO, Bangladesh standard) drinking water standard. In this simulation, the water purification cost was found $0.002/litre (or 0.016BDT/litre), which is really low compared to the bottled water system that are around $0.025/litre or 2.0BDT/litre in Bangladesh. Moreover, the electricity cost of the system was found to be $0.13/kWh from the solar system, which accredits it as an economically viable solution as compared to other power generation systems available in the region.

Acknowledgement

The authors are grateful to the Renewable Energy Lab (REL) of the Department of Electrical & Electronic Engineering

(EEE), Environmental Lab of Department of Civil Engineering (CE) and Institute of Energy Technology (IET), at Chittagong University of Engineering & Technology (CUET), Chittagong, Bangladesh for the support to carry out this research work.

References

[1] N.A. Nada, A. Zahrani and B. Ericsson, "Experience on pre- and post-treatment from sea water desalination plants in Saudi Arabia". *Desalination*, Vol. 66, pp. 365–383. 1987.

[2] World Health Organization (WHO) (2018, May). Retrieved from http://www.who.int/en/ Accessed on 25th July 2018.

[3] A. D. Khawaji, I. K. Kutubkhanah, & J. Wie, "Advances in seawater desalination technologies". *Desalination,* Vol.221 Issue.1(3). (pp.47-69). 2008.

[4] M. A. H. Baky, M. M. Rahman & Islam, A. S. "Development of renewable energy sector in Bangladesh: Current-status and future potentials". Renewable and Sustainable Energy Reviews, 2017. Vol.73, (pp.1184-1197).

[5] Bangladesh Power Development Board (BPDB). (2018, July). Retrieved from http://www.bpdb.gov.bd/bpdb. Accessed on 25th July 2018.

[6] K. M. Kabir, M. A. Matin, M. S. U. Chowdhury, & R. Chowdhury, "Design and Analysis of Grid Connected Biomass System Utilizing Chittagong Municipal Food Waste". 3rd International Conference on. Electrical Information and Communication Technology (EICT), Khulna, Bangladesh, (pp.1-4). 2017. IEEE

[7] K. M. Kabir, M. A. Matin & N. Amin, "A Solar Powered Desalination System for Remote Region in Bangladesh". 4th International Conference on Mechanical Engineering and Renewable Energy (ICMERE), Chittagong, Bangladesh. (pp. 1-5), 2017. [Available]. *http://www.cuet.ac.bd/icmere/files2017f/ICMERE2017-PI-401.pdf.*

[8] Alkaisi, A., Mossad, R., & Sharifian-Barforoush, A. "A review of the water desalination systems integrated with renewable energy". Energy Procedia, Vol.110, (pp.268-274). 2017.

[9] Zubair, A., Tanvir, A. & Hasan, M. M. "Optimal Planning of Standalone Solar-Wind-Diesel Hybrid Energy System for a Coastal Area of Bangladesh". International Journal of Electrical and Computer Engineering (IJECE). Vol.2(6), pp.(731-736). 2012.

[10] K. M. Kabir, A. Nath, S. Mazumder, & M. O. Islam. "Modelling & simulation of a grid connected hybrid power plant with photovoltaic, wind & diesel power for Cox's Bazar". *International Conference on Electrical, Computer & Telecommunication Engineering (ICECTE),* Rajshahi, Bangladesh. (pp. 1-4). 2016. IEEE.

[11] K. M. Kabir, S. Mazumder, S. U. Chowdhury, & M. R. Haq. "Design & simulation of photovoltaic, wind, battery, grid connected hybrid power system for Patenga, Chittagong, Bangladesh". 2015 International Conference on Advances in Electrical Engineering (ICAEE), (pp. 1-4). Dhaka, Bangladesh. 2015. IEEE.

[12] Toray Software. (2018, July). Retrieved from https://ap3.toray.co.jp/toraywater/. Accessed on 25th July 2018.

[13] A. A. Setiawan, Y. Z. Chem, & V. Nayar, "Design, economic analysis and environmental considerations of mini-grid hybrid power system with reverse osmosis desalination plant for remotes areas". *Renewable energy* (2009) vol.34. pp. (374-383).

[14] NASA surface meteorology and solar energy. (2018, July). Retrieved from http://eosweb.larc.nasa.gov. Accessed on 25th July 2018.

[15] The Environment Conservation Rules. (1997). Department of Environment, People's Republic of Bangladesh. Retrieved from https://www.elaw.org/system/files/Bangladesh+--+Environmental+Conservation+Rules,+1997.pdf . Accessed on 25th July 2018.

[16] K. M. Kabir, M. A. Matin, H. Misran & N. Amin "Solar Photovoltaic Assisted Cost-efficient Brackish Water Purification System". 4th International Conference on Electrical Engineering and Information & Communication Technology (iCEEiCT), (pp. 1-4). Dhaka, Bangladesh. 2018. IEEE.

[17] K. M. Kabir, "Design and Performance Analysis of Renewable Energy Resources for Pure Drinking Water in Coastal Region". *M.Sc. Eng. Thesis,* Institute of Energy Technology, Chittagong University of Engineering & Technology (CUET). Chittagong, Bangladesh. 2018.

[18] Bangladesh Power Development Board "Annual Report 2016-17" (2018, 25th July) Retrieved from http://www.bpdb.gov.bd/download/annual_report/Annual%20Report%202016-17%20(2).pdf. Accessed on 25th July 2018.