Study of performance evaluation, economic and environmental impact of 1.68 kWp DC operated submersible centrifugal solar pump with autotracker using low cost DAS

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Abstract: The widespread application of renewable energy sources requires the use of low cost data acquisition system (DAS) both for monitoring the system operation and control of its operation. The objective of this paper is to evaluate the performances of the 1.68 kWp DC operated submersible centrifugal solar pump with autotracking system using microcontroller based home-made low cost universal DAS. In order to evaluate the actual discharge capacity with respect to designed capacity under local solar irradiance and photovoltaic array power output, it is not convenient to gather years' data manually. The developed home-made low cost DAS is used to collect data every minute and to store the average of this data to the personal computer in a suitable manner. In order to verify the performances of the 1.68 kWp DC operated submersible centrifugal solar pump with autotracking system, solar irradiance, discharge capacity and efficiency of the pump with respect to time is evaluated from the collected data using the DAS. Results found that off grid areas of Bangladesh, PV based solar pumping systems are spin off economic and environmental benefits compared with diesel based water pumping system.

Keywords: low cost DAS; solar pump; autotracker; performance monitoring; economic and environmental impact

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He has broad experiences in thermal hydraulics and is skilled in heat transfer and fluid flow characteristics. He has about eight years work experiences on research reactor operation and maintenance activities, nuclear reactor safety, security and safeguards matters during his past job at Bangladesh Atomic Energy Commission. He is also involved with strengthening utilisation of renewable energy especially solar energy in the country.

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1 Introduction

The continuous increase in the cost and demand for energy has prompted rising research and development interest in the utilisation of non-conventional energy sources, mainly solar energy in Bangladesh (Hussain et al., 1994; Islam et al., 2012). Being situated in the tropical climate zone, the country has huge opportunity to use solar energy over a long period in the year. Earlier, it was thought that solar energy could be used only to electrify some remote and island areas where regular power line is unavailable (Habib, 2012; Bahauddin and Salahuddin, 2012). But it is rationale now-a-days to install solar energy in new built up urban and sub-urban areas which will reduce pressure on the national electricity grid and help attaining self-sufficiency in power sector as well. In Bangladesh, electricity is mainly generated from the thermal power plants where the primary fuels are based on indigenous natural gas (≈ 85%; MPEMR, 2011). Realising the limitation of primary sources of energy, the government of Bangladesh has decided in the national energy policy to get at least 10% of the total energy supply from the renewable sources by 2020 (MPEMR, 2008; MPEMR, 2002). For this, the government has given directives the concern authorities to strengthen the utilisation of solar energies and development its related technology through R&D activities (principal secretary's letter, prime minister's office, letter no. 32.39.16.00.00.08.2009-91(48)). Presently usage of solar energy in a large scale shows promising not only for lighting solution but also for irrigation and thermal purposes. There are presently nine companies[1] who are assembling solar modules with an annual production capacity of 80–90 MWe. Considering the realistic national energy policy, government directives, encouragements and above all subsequent steps taken so as to develop the renewable energy sector especially solar technology, cost of solar electricity is decreasing gradually (Islam, 2012; IDCOL, 2011). It is now expected that cost of solar electricity will be reached within the financial capability of the rural people (Hossain, 2012; Islam, 2011).

Bangladesh is an agricultural country and proper irrigation is the most important matter for cultivation. There are about 1.33 million irrigation pumps [*Daily Prothom Alo*, (2015), p.20; Daily Jugantor, (2012), p.5] running in the country. About 85% pumps are running by diesel fuel and the rest is running by rural electrification network (BADC 2011; Mazed, 1987). For this, the government has to give incentives on diesel fuel. It is roughly estimated that the government has to buy 1 billion litre diesel fuels every year [*Daily Prothom Alo*, (2015), p.20; *Daily Jugantor*, (2012), p.5] to run the total irrigation pumps. On the other hand, about 800,000 tons diesel is used for irrigation which produces about 2.0 million tons of CO_2 (Sadrul Islam and Ahiduzzaman, 2011). Due to electricity crisis and import dependent diesel price is fluctuating in nature, it is likely possible to irrigate only 59 % of cultivable land properly (Habib, 2012; Hossain et al., 2003; Bahauddin and Salahuddin, 2012). Rest 41% lands are not irrigated properly. At present groundwater contributes to 77% of total irrigated area (Mazed, 1987). There is a strong possibility to expand irrigation area and for boosting up crop production for ensuring food security.

In this context, pumps running with solar electricity can perform important role for rural irrigation system. A 1.68 kWp solar power driven submersible multistage centrifugal pump with single axis autotracker has been installed at the premises of the Bangladesh Atomic Energy Commission (BAEC) Agargaon, Dhaka to meet the daily consumption of about 15,000 litres of water (Islam, 2010; Ahmed, 2011). Performance studies of the 1.68 kWp capacity submersible multistage centrifugal pumps with DC motor-controller for water-discharge capacity of 40 m^3/hr (40,000 L/day) at 30.48 meter static head with autotracker at the premises of the BAEC are needed to be carried out to know its techno-economic aspects and environmental impact (Mahbub et al., 2012; Hossain et al., 2012; Islam, 2011). But there is no such low cost universal data acquisition system (DAS) available in the local market. DAS is an imported technology for most developing countries like Bangladesh, meaning high cost and a barrier to the dissemination of such systems. The design and implementation of a low cost DAS is motivated by the need to offer an alternative for commercial systems, which are more expensive, usually imported and have proprietary software (Rosiek and Batlles, 2008; Trotter and Carson, 1985). In addition, commercial DASs do not allow amendments and adjustments to hardware nor software. For this, the designed and developed home-made low cost universal DAS for applications to a decentralised renewable energy plant for monitoring parameters and system efficiency with USB is being used by the authors. Development of such a low cost and user friendly data acquisition software demands very effective and useful research as there is no local initiative taken for record keeping the data of solar electricity driven system. The objective of this paper is to evaluate the performances of the 1.68 kWp DC operated submersible centrifugal solar pump with autotracking system using microcontroller based home-made low cost universal DAS. Set up of such a DC operated submersible centrifugal solar pump with autotracking system for pumping water is the first of its kind in the country. Variations of solar intensities and pump discharge capacities with regard to time are gathered and then analysed in this study. Based on these data, economic and environmental impact is assessed for sustainable development of the country.

2 Methodology

Five parameters are needed for complete evaluation of the performances of the solar water pumping system such as solar irradiance, water flow rate, PV panel voltage, current and ambient temperature. Data are first collected, conditioned using precision electronic circuits and then transmitted to the personal computer (PC). The information from the data logger is transmitted via direct connections such as USB, RS232, RS485 to the PC, where they are processed using the appropriate data acquisition software. Suitable software is then used to further process, display and store the collected data in the PC. Figure 1 shows the schematic diagram of the water pumping system in connection with the five measuring sensors and the PC. The information from the sensors goes to the microcontroller, where it is processed and passed to the external 24C32A EEPROM memory and later to the PC via the RS 232 interface (Belmili et al., 2010; Koutroulis et al., 2003, Koutroulis and Kalaitzakis, 2003). The treated data are converted into their real physical values (current, voltage, irradiance, etc.) and used to analyse the performance of the considered photovoltaic water pumping systems. Figure 2 shows a general scheme of the various possibilities for field data collection and its transmission to a PC.

Figure 1 Data from the PV water pumping station to the personal computer

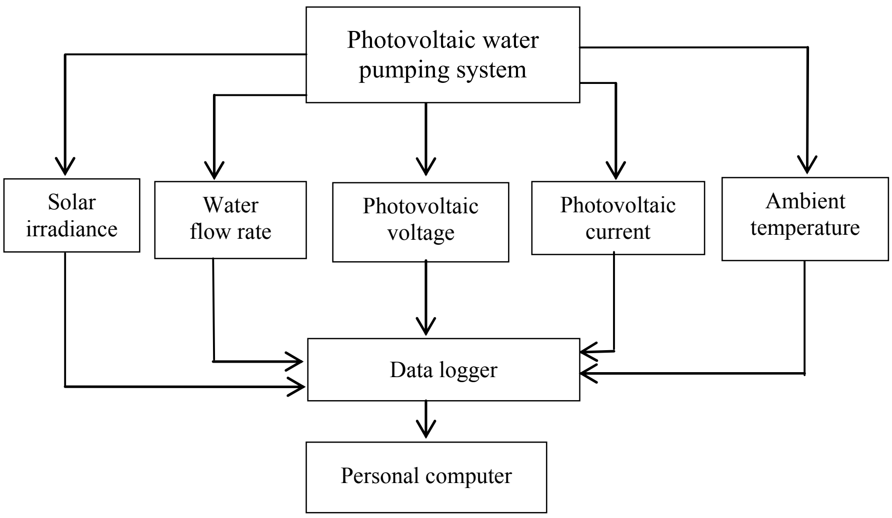
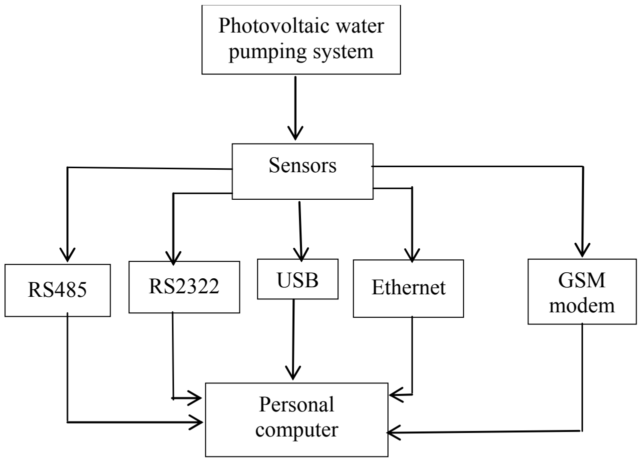


Figure 2 Field data transmission possibilities



3 Results

3.1 Performance analysis

The performance data recorded in the data logger at one hour time interval and then transmitted from the photovoltaic water pumping systems to the PC via the USB port were analysed. Table 1 shows the data obtained from the PV water pumping system using DAS from 28–29 September 2011.

Table 1 Recorded data of solar intensity and flow rate on 28–29 September 2011

Day	*Time*	*Solar intensity*		*Flow metre reading (L/hr)*	*Total volume discharge (litres)*
		(lux)	*(W/m²)*		
28-10-2011	10:00:00 AM	78,000	616.2	652	4,561
	11:00:00 AM	82,000	647.8	690	
	12:00:00 PM	87,000	687.3	780	
	1:00:00 PM	98,000	774.2	867	
	2:00:00 PM	72,000	568.8	643	
	3:00:00 PM	56,000	442.4	463	
	4:00:00 PM	42,000	331.8	276	
	5:00:00 PM	36,000	284.4	190	
29-10-2011	10:00:00 AM	78,000	616.2	752	5,072
	11:00:00 AM	84,000	663.6	788	
	12:00:00 PM	95,000	750.5	660	
	1:00:00 PM	102,000	805.8	990	
	2:00:00 PM	88,000	695.2	649	
	3:00:00 PM	69,000	545.1	588	
	4:00:00 PM	52,000	410.8	405	
	5:00:00 PM	40,000	316	240	

There is no direct unit conversion between lux and W/m2. It mainly depends on the wavelength or color of the light. However, for sunlight, there is an approximate conversion of 0.0079 W/m2 per lux. The pump output is measured using equation (1).

$$\text{Pump Output, } P_o = \rho QH \text{ (watts)} \quad (1)$$

where,

ρ specific weight of water = 9810 N/m^3

Q volumetric flow rate in m^3/s

H static head = 30.48 meters

From Figure 3, it can be seen that the light intensity is the maximum at approximately 11 am to 2 pm. The overall energy converting efficiency of the panel was also the highest during this time. The daily quantity of water pumped by the set up was 10 m^3 on an average. From Figure 3, it is found that the maximum mean flow rate occurs at midday in summer with 20 m^3/day. Table 2 shows the variation of flow rates with regard to solar intensity and time in hour from 15–16th April 2012. The performance data registered in the data logger at one hour interval and transmitted from the photovoltaic water pumping systems to the PC via the USB interface were analysed in Figures 4 to 7. Figures 4 and 5 shows the variation of total discharge capacity of water with respect to the solar intensity (W/m^2) from 15–16th April 2012, respectably.

Figure 3 Variation in solar intensity and flow rate on 28–29 September 2011

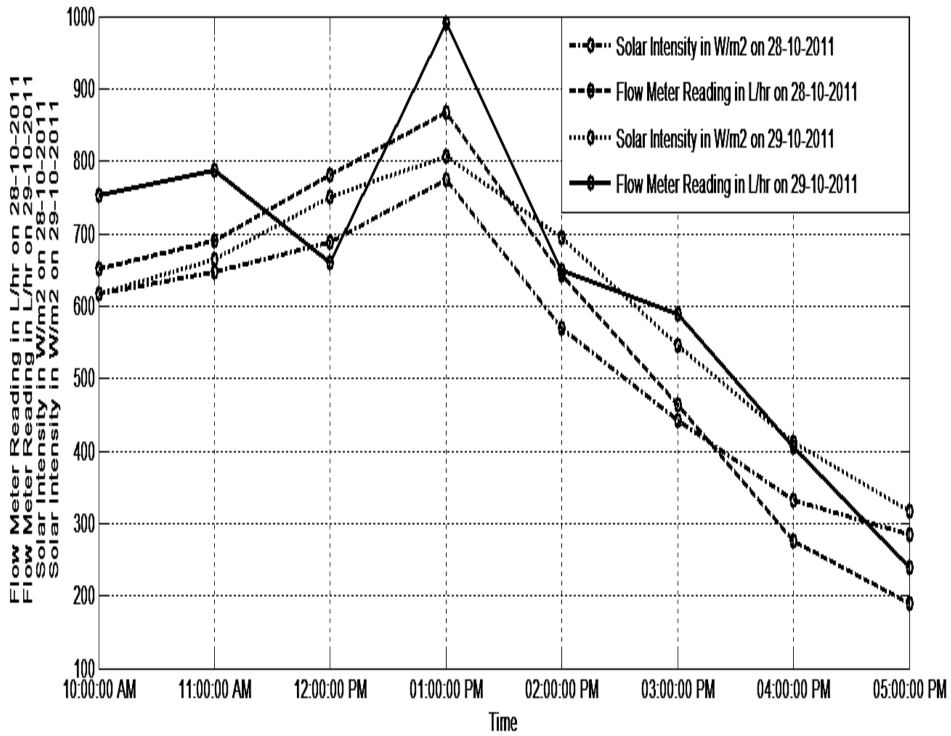


Table 2 DAS reading on 15–16th April 2012

Day	*Time*	*Solar intensity*		*Flow meter reading (L/hr)*	*Total volume discharge (L)*
		Lux	*W/m²*		
15-04-2012	10:00	78000	616.2	652	4561
	11:00	82000	647.8	690	
	12:00	87000	687.3	780	
	13:00	98000	774.2	867	
	14:00	72000	568.8	643	
	15:00	56000	442.4	463	
	16:00	42000	333.1	276	
	17:00	36000	284.4	190	
16-04-2012	10:00	78000	616.2	752	5072
	11:00	84000	663.6	788	
	12:00	95000	750.5	660	
	13:00	102000	805.8	990	
	14:00	88000	695.2	649	
	15:00	69000	545.1	588	
	16:00	52000	410.8	405	
	17:00	40000	316.2	240	

Figure 4 Variation in solar intensity vs total discharge on 15th April 2012

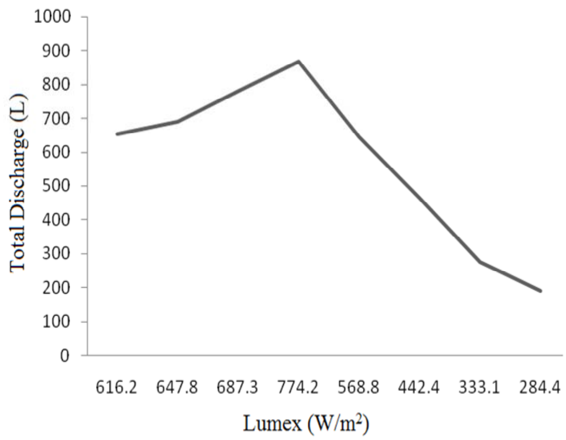


Figure 5 Variation in solar intensity vs total discharge on 16th April 2012

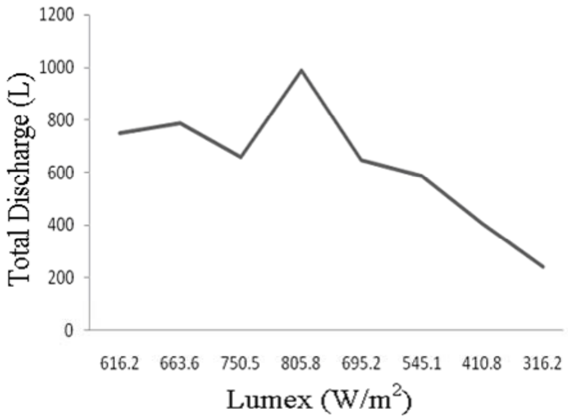


Figure 6 Variation of total discharge vs days of a week from 15th–21st April 2012

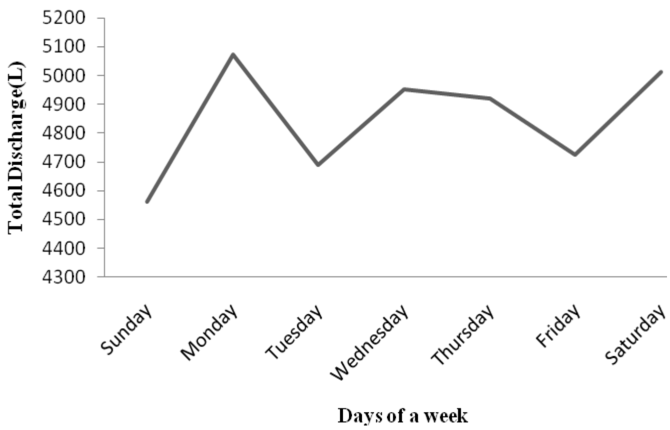
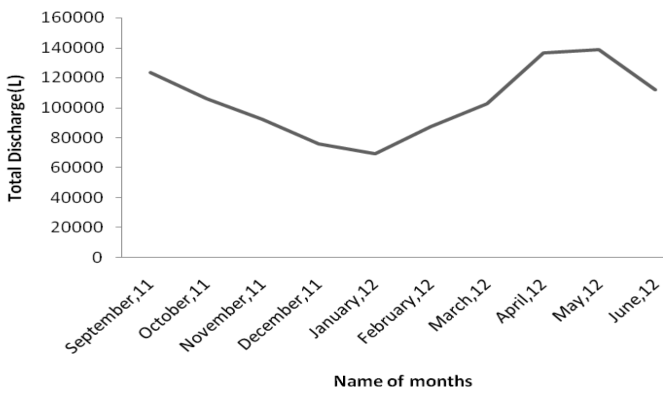


Figure 7 Variation of total discharge vs month from September 2011 to June 2012



It shows that water discharge rate varies with the solar intensity and it was the maximum when solar intensity was the maximum. Day-wise total discharge capacity of water is stated in Figure 6. Total discharge capacity of water at different months of the year 2011 and 2012 is also stated in Figure 7. Wide variation of the discharge capacity of water was observed as it depends on solar intensity. In May 2012, the total discharge capacity of water was the highest which amounts to 1,38,925 litre.

3.2 Economic feasibility

The 1.68 kW solar driven submersible pump with autotracker is capable to discharge 15,000 L of water per day with a life time of 25 years and having a less maintenance cost. The cost per litre water lifting can be calculated using equation (2).Now if we calculate the amount that required for lifting 15,000 L of water, it costs almost 2.50 US Dollar (USD:$) whereas for the grid electricity it costs nearly 0.50 $.

$$\text{Unit cost} = \frac{\text{Total water pumped in a year}}{(\text{Total cost in a year})} \tag{2}$$

Based on this study, PV water pumping system is very much promising for irrigation purposes where grid connection is almost absent in rural areas. This is because, during the dry season (summer) there is a huge demand of electricity. And it is a regular feature of shortfall of grid electricity throughout the country which hinders cultivation of land. Cost of diesel even becomes higher than the PV system during the dry season. In order to irrigate 1 hectare (ha) of cultivable land for one season from a seasonal depth of 675 mm and volumetric entitlement (mm/ha) of 100 mm/ha with a flow rate up to 0.6 l /sec/hectare, required amount of water (Q) can be calculated using equation (3).

$$\begin{aligned} Q &= \frac{(\text{Area (hectares)} \times \text{Seasonal depth })}{\text{Volumetric entitlement (mm/ha)}} \\ &= 1,68,75,00,000 \text{ L of water} \end{aligned} \tag{3}$$

It is found that for lifting 1,68,75,00,000 L of water, it costs about 6,000 $, 9,00 $ and 6,625 $ for the PV pumping system, for the grid electricity and for the diesel system, respectively. Techno-economic studies with regard to the different sources of energy based pumping system (grid electricity, diesel) for pumping the same amount of water for cultivable land having same seasonal depth; volumetric entitlement and flow rate are depicted in Table 3. It is seen from Table 3 that grid electricity is the cheapest source for irrigation compared to other systems like PV or diesel. In Bangladesh where grid electricity is not so available especially in the rural areas, PV system would be a good choice as it is cheaper than the diesel one.

Table 3 Economic feasibilities for irrigation at different energy sources

Energy source	*Amount of water*		
	1 ha ($)	*5 ha ($)*	*20 ha ($)*
PV pumping system	6,000	25,200	1,00,800
Grid electricity	900	1,900	4,300
Grid electricity (3 km extension)	11,000	11,600	13,700
Diesel	6,700	8,500	14,700

3.3 Environmental impact

Now-a-days global warming and climate change is a burning issue throughout the world. And it is carbon which is the main culprit for global warming. Bangladesh being the most vulnerable country to global warming should also focus on saving carbon.

The combustion reaction of diesel and LPG (Liquefied petroleum gas) is given as:

Diesel: $C_{50}H_{93} + 193/4\ O_2 \rightarrow 50\ CO_2 + 93/2\ H_2O$

1 mol $C_{50}H_{93}$ (694.27342 g/mol) $\rightarrow$ 50 mol CO_2 (44 g/mol)

$\Rightarrow 694.27\text{g} \rightarrow 50 \times 44 = 2200$ g

$\Rightarrow (3168.8 \times 0.832 = 2636.44)$

$1000/694.27 \times 2200 = 3168.8$ g

1 kg of diesel produces 3.17 kg of CO_2

1 litre of diesel produces 2.64 kg of CO_2

LPG GPL: $C_3H_8 + 5O_2 \rightarrow 3\ CO_2 + 4\ H_2O$

1 mol C_3H_8 (44 g/mol) $\rightarrow$ 3 mol CO_2 (44 g/mol)

$\Rightarrow 44\text{ g} \rightarrow 3 \times 44 = 132\text{g} \Rightarrow 1000/44 \times 132 = 3000$ g

1 kg of LPG GPL produces 3 kg of CO_2

It is found that the amount of CO_2 emission is 573.7 g/kWh. So, this plant will save about 1.2 ton CO_2 emission potential from the atmosphere in a year. In 25 years, it will save about 30 ton CO_2 emission.

4 Discussions

Performance analysis both for monitoring the solar based water pumping system operation and control of its operation using microcontroller based low cost universal DAS is found very effective tool compared with other available commercial DASs (Belmili et al., 2010, Koutroulis et al., 2003, Koutroulis and Kalaitzakis, 2003, Mukaro et al., 1998, Mukaro and Carelse, 1999, Rosiek and Batlles, 2008, Trotter and Carson, 1985). This is because, performance analysis using commercial DASs means more expensive and has proprietary software that does not allow amendments and adjustments to hardware nor software. This situation also incurs additional cost of the solar energy project which hinders growth of its widespread applications especially in the developing countries. Another unique feature for performance analysis using home made low cost universal DAS compared with other commercial DASs can easily optimise the local meteorological data. Thus, aids in minimising the system cost and maximising the operational reliability under intermittent power generation conditions. However, more importantly for ensuring smooth recording of data of the remote renewable energy system needs uninterruptible power supply to run the DAS and PC. Otherwise, continuous data recording process will be disrupted. Presence of dirt in the air seriously hinders the performances of the solar panels for power conversion. For this, regular maintenance of the panels is a must otherwise life time of the panels will be sharply shortened. Results found from the performance analysis in terms of technical and economic viewpoint, utilisation of solar energy is promising and comparable in the case of developing countries where a chronic power shortage is a regular feature. In order to control the carbon emission rate, maintaining future energy security and sustainable economic growth, potential countries in the areas of renewable energies have increased their investment a few fold. As a result, global carbon emission rate (32 giga ton) in 2014 was unchanged which was equal to the preceding year [*Daily Prothom Alo*, (2015), p.15]. As sun appears mostly round the year in Bangladesh, the country is turning into solar nation gradually (IDCOL, 2011). Bangladesh is achieving a remarkable progress towards the controlling of carbon emission rate. More than 100 MWp installed capacities (IDCOL, 2011) of solar energy based plants both for lighting and irrigation purposes are working in the country, which is a significant step for a cleaner and greener environment and sustainable development.

5 Conclusions

The use of home-made low cost DAS facilitates the spread of the measurements in renewable energy plants, thus allowing recognised local energy resources such as solar irradiance and wind speed to monitor the power conversion efficiency and to analyse the financial advantage of using such plants. During the performance analysis of the 1.68 kW capacity brushless DC operated submersible centrifugal pump-motor with single axis solar autotracking system, only microcontroller based DAS is locally manufactured. Other components such as 1.68 kWp capacity brushless DC operated submersible centrifugal solar pump-motor, monocrystalline solar panels and single axis solar autotracking system and MPPT motor controller are imported ones. From the analysis of the gathered data, it is found that cost incurs almost 2.50 $ for pumping 15,000 litres of water to a high rise eight storied office building using the1.68 kWp capacity PV based solar pumping with autotracker system while for pumping the same amount of water using grid electricity system, it costs nearly 1.25 $. Applying these results to the irrigation areas, comparative studies among diesel based water pumping system, grid electricity based water pumping system and PV based pumping system are performed. In order to irrigate 1 hector of cultivable land for one season from a seasonal depth of 675 mm and volumetric entitlement (mm/ha) of 100 mm/ha with a flow rate up to 0.6 l/sec/hector, it is required about 1,68,75,00,000 L of water. To pump such an amount of water, cost incurs about 6,000 $ for the PV pumping system, 900 $ for the grid electricity and 6,625 $ for the diesel based pumping system. Result shows that cost per unit energy (kWh) by solar power could be reduced substantially if locally made solar panels, sun tracking system and other accessories can be used. The results have shown very much potential applications to rural irrigation pumps running by solar power rather than diesel. The 1.68 kWp solar water pumping system will save about 1.2 ton CO_2 emission potential from the atmosphere. In 25 years, it will save about 30 ton CO_2 emission which is a significant step for sustainable development of the country by controlling the rate of carbon emission in the atmosphere. The plant is used for direct application of solar energy and other related R&D activities.

References

Ahmed, S.I. (2011) 'Introduction to solar pump in Bangladesh', Paper presented at the *National Seminar on Renewable Energy*, Dhaka, Bangladesh, 6–8 April 2011.

BADC (2011) *Summary of Irrigation Equipment Used, Area Irrigated and Benefited Farmers: 2010–11*, Bangladesh Agricultural Development Corporation (BADC), Shech Bhavan, Dhaka [online] http://www.badc.gov.bd.irrigation-equipment.htm (accessed 13 October 2012).

Bahauddin, K. and Salahuddin, T. (2012) 'Prospect and trend of renewable energy and its technology towards climate change mitigation and sustainable development in Bangladesh', *International Journal of Advanced Renewable Energy Research*, Vol. 1, No. 3, pp.14–25.

Belmili, H. et al. (2010) 'Design and development of a data acquisition system for photovoltaic modules characterization', *Renewable Energy*, Vol. 35, pp.1484–1492.

Daily Jugantor (2012) 22 May, p.5 [online] http://www.jugantor.com/archive/2012/05/22/index.htm (accessed 24 May 2012).

Daily Prothom Alo (2015) 27 March, pp.15, 20 [online] http://epaper.prothomalo.com/view/dhaka/2015-03-27/20 (accessed 30 March 2015).

Habib, A.A. (2012) 'Prospects and impediments renewable energy in Bangladesh', Proceedings of the *6th International Mechanical Engineering Conference & 14th Annual Paper Meet (6IMEC&14APM)*, Dhaka, Bangladesh, 28–29 September 2012, IMEC&APM-ET-03.

Hossain, M.A. (2012) 'Techno-economic study of small scale solar pump for irrigation', A key-note paper presented in the Seminar, Organized by Institute of Engineers, Gazipur Centre, Gazipur, Dhaka, Bangladesh.

Hossain, M.A. et al. (2003) 'Solar energy in agriculture', Proceedings of the *3rd International Conference on Renewable Energy for Sustainable Development (ICRESD)*, Dhaka, Bangladesh, 2–4 October 2003.

Hossain, M.A. et al. (2012) 'Performance evaluation of solar pump for irrigation in rice and vegetables', Proceedings of the *6th International Mechanical Engineering Conference & 14th Annual Paper Meet (6IMEC&14APM)*, Dhaka, Bangladesh, 28–29 September 2012, IMEC&APM-ET-19.

Hussain, M., Rahman, L. and Bhuiyan, M.M.H. (1994) 'Performance of a small PV pump at Dhaka', *Renewable Energy*, Vol. 5, No. 3, pp.1675–1677.

Islam, A. (2011) 'Report of the Proceedings on *4th Japan – SAARC Symposium on Regional Cooperation in Energy Efficiency and Renewable Energy*, in collaboration with SAARC Secretariat, Kathmandu and Government of Japan, Dhaka, Bangladesh, 30–31 March 2011.

Islam, S. (2010) 'Solar energy utilization and development of related technology in Bangladesh', Paper presented at the *National Seminar on Prospect of Energy Auditing and Alternative Energy to Meet the Present Energy Crisis in Bangladesh, Military Institute of Science and Technology (MIST)*, Dhaka, Bangladesh, 09 October 2010.

Islam, S. et al. (2012) 'Manufacturing techniques of low-cost si-based crystalline type solar cell in Bangladesh', *Journal of Mechanical Engineering, Transaction of the Mechanical Engineering Division*, The Institution of Engineers, Bangladesh, Vol. ME 42, No. 1, pp.29–37.

Koutroulis, E. and Kalaitzakis, K. (2003) 'Development of an integrated data-acquisition system for renewable energy sources systems monitoring', *Renewable Energy*, Vol. 28, No. 1, pp.139–152.

Koutroulis, E. et al. (2003) 'Development of a data acquisition system for remote monitoring of renewable energy systems', *Instrument Measurement*, Vol. 34, pp.75–83.

Mahbub, Z. et al. (2012) 'Comparison between conventional power generation and renewable energy power generation in Bangladesh', *Journal of Engineering Research and Applications (IJERA)*, Mar-Apr, Vol. 2, No. 2, pp.896–902.

Mazed, M.A. (1987) 'Performance evaluation of ARCO solar pump model CSB 50D in Bangladesh', *Bangladesh Journal of Agricultural Engineering*, Vol. 1, No. 1, pp.17–20.

Ministry of Power, Energy and Mineral Resources (MEPMR) (2002) *People's Republic of Bangladesh*, October, Renewable Energy Policy [online] http://www.en.wikipedia.org/wiki/Renewable_energy_policy_of_Bangladesh (accessed 15 December 2015).

Ministry of Power, Energy and Mineral Resources (MPEMR) (2008) *People's Republic of Bangladesh*, March, National Energy Policy [online] http://www.powercell.gov.bd/index.php?page_id=213 (accessed 15 December 2015).

Ministry of Power, Energy and Mineral Resources (MPEMR) (2011) *People's Republic of Bangladesh*, February, Power System Master Plan 2010 (PSMP2010) [online] http://www.ogel.org/legal-and-regulatory-detail.asp?key=13440 (accessed 15 December 2015).

Mukaro, R. and Carelse, X.F. (1999) 'A microcontroller-based data acquisition system for solar radiation and environmental monitoring', *IEEE Trans. Instrum. Meas.*, Vol. 48, pp.1232–1238.

Mukaro, R. et al. (1998) 'First Performance analysis of a silicon-cell microcontroller based solar radiation monitoring system', *Solar Energy*, Vol. 63, pp.313–321.

IDCOL (2011) *Renewable Energy Projects* [online] http://www.idcol.org/prjshsm2004.php (accessed March).

Rosiek, S. and Batlles, F.J. (2008) 'A microcontroller based data acquisition system for meteorological station monitoring', *Energy Convers. Manag.*, Vol. 49, pp.3746–3754.

Sadrul Islam, A.K.M. and Ahiduzzaman, M.D. (2011) 'GHG emission and renewable energy sources for sustainable development in Bangladesh', Proceedings of the *International Conference on Environmental Technology and Construction Engineering for Sustainable Development (ICETCESD)*, Sylhet, Bangladesh, SUST.

Trotter, C.M. and Carson, W.W. (1985) 'Data acquisition from a parallax bar via an RS232C interface', *Rev. Sci. Instrum.*, Vol. 56, pp.2154–2156.

Notes

1 Rahimafrooz Renewable Energy, Electrosolar Power, East Coast Group, Ava Renewable Energy, Greenfinity Energy, Shouro Bangla, GTS Solar, BANECO Solar Energy, Parasol Energy.