UDC-BDU Partnership:
Renewable Energy Project at Bahr Dar University

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ABSTRACT: The paper describes the realization of a standalone, PV/Wind powered water delivery system, undertaken jointly by the University of the District of Columbia in Washington, DC, USA and Bahir Dar University in Ethiopia. This UDC-BDU partnership was supported by a Seed Grant from the US Embassy in Ethiopia. The project is a model that can be duplicated in various rural communities which need ambulant water delivery. The proposed water delivery includes potable water to rural communities and cattle, as well as water for small scale drip-irrigation. The design introduces novel features providing versatility and mobility to the system. The paper describes also the academic merit of the project by highlighting its integration in the BDU's undergraduate and graduate power engineering curricula.
Keywords: Stand-alone PV systems, Water Pumping

1 INTRODUCTION

This paper summarizes the collaborative work between the University of the District of Columbia's (UDC) Center of Excellence for Renewable Energy and Department of Electrical and Computer Engineering of the Institute of Technology at Bahir Dar University, in Ethiopia supported by a seed-grant support from the US-Embassy in Addis Ababa, Ethiopia through a press release issued in March 2011 [1]. The proposal for establishing this partnership was crafted following a one year Fulbright fellowship of the first author at Bahir Dar University in 2009-2010, when it was deemed appropriate to continue the effort of introducing research on the application of solar and wind power based water pumping systems for alleviating the population's needs related to potable and irrigation water in rural Ethiopia. Both UDC's and BDU's Presidents supported the proposed partnership in 2011. Similar projects were previously undertaken in collaboration with a local NGO and the Addis Ababa University [2]. The current project has used lessons learned from the initial projects and established a model standalone PV and wind powered water pumping system on the campus of the BDU's Institute of Technology (BDU-IOT) and subsequently designed a suitable "mobile" standalone system that could be servicing several localities in the State of Amhara, with existing spring water or presenting a good potential of accommodation shallow water wells.

2 INITIAL PREPARATIONANS AT BDU

2.1 Initial vision

The research team was promptly formed at BDU-IOT, following the partnership agreement and soon after a close cooperation was established with UDC's CERE.

Both sides acknowledged that photovoltaic energy source (PV) systems can be used for pumping water for irrigation of land, as well as for pumping drinking water.

It was recognized that access to a safe and clean water supply is one of the primary factors in improving the health and quality of life in rural communities. In the developing world, including Ethiopia, there is an acute need of potable water in rural communities, which are generally not connected to a centralized system, for supply drinking water. The principal means of water supply in the developing world are: the hand pump for smaller demands; and the diesel-engine-driven pump for larger quantities.

Solar PV pumping can be more appropriate than these technologies in many applications. As communities expand, hand pumping may not be sufficient even if the well and spring water capacity is large.

The advantages of PV base pump systems in rural communities in developing countries include:

- No gap between the first investment and the first production of electricity, because electricity is available immediately after PV system construction;
- No need for expensive solar tracking systems;
- Direct room temperature conversion of light to electricity through a simple solid state device;
- Less maintenance cost due to absence of moving parts and longevity of solar panels;
- Ability to function unattended for a long period of time;
- Modular nature in which desired current, voltage and power levels can be achieved by more integration;
- No fuel consumption and therefore environmentally friendly;
- Wide power handling capability;
- High power to weight ratio;
- Solar water pumping systems need little supervision requiring only periodical checking. Solar pumps automatically start soon after sunrise and continue to work unattended until sunset; and
- Simple water transfer from dam to tank

2.2 Double reservoir PV pumping system

The project undertaken by the UDC-BDU partnership has benefited from the lessons learned during the implementation of PV based water pumping systems in Ethiopia. In fact, since 2008, UDC had in partnership with a local NGO and the Addis Ababa University, had helped design PV and wind energy based water pumping systems in some localities in South Western Showa zone, in the state of Oromia [2]. A few of these systems were visited by the BDU research team while the team was preparing to embark on the UDC-BDU partnership work.

The main features of these successful projects include:

- Effective use of DC pumps for shallow wells of limited head (~100m), thus avoiding the use of inverters; and
- A double reservoir PV, two-DC pump, pumping system as in Fig.1,for accommodating maximum efficiency of the use of the DC pumps;

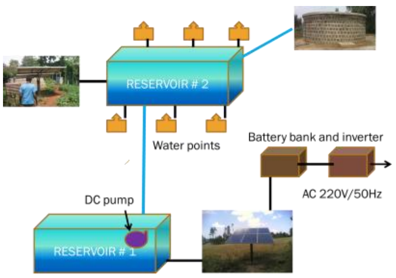

Figure 1: Double reservoir water delivery system

The topography of most rural areas in Ethiopia, where shallow wells can be envisaged lends itself to the use of such a double-reservoir water pumping system as depicted in Fig 2.

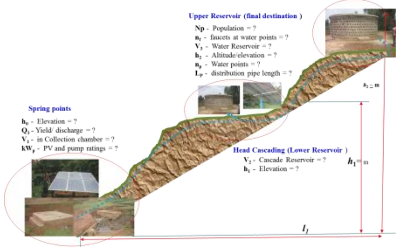

Figure 2: Typical topography of rural Ethiopia, suitable to double-reservoir systems

2.2 Model designed at BDU-IOT

The BDU-IOT team proceeded in designing a model PV and Wind powered water pumping system for data collection and feasibility study. They received under the partnership provisions the following items:

- One 11SFQ-2 Grundfos, 900W, submersible water pump, operating in DC/AC(50-60Hz) mode and CU200 Controller;
- One wireless Vintage Pro2 Plus weather monitoring system;
- Four 6T Helios 245W solar modules;
- One Xantrex Prosine 1800I, 24V inverter; and
- One Xantrex C60 Inverter.

The system constructed at BDU, includes a 2-level water barrel system to emulate a 2-level water pumping system, a solar module "manual" tracking system as depicted in Fig. 3 of the paper should be informative and concise.

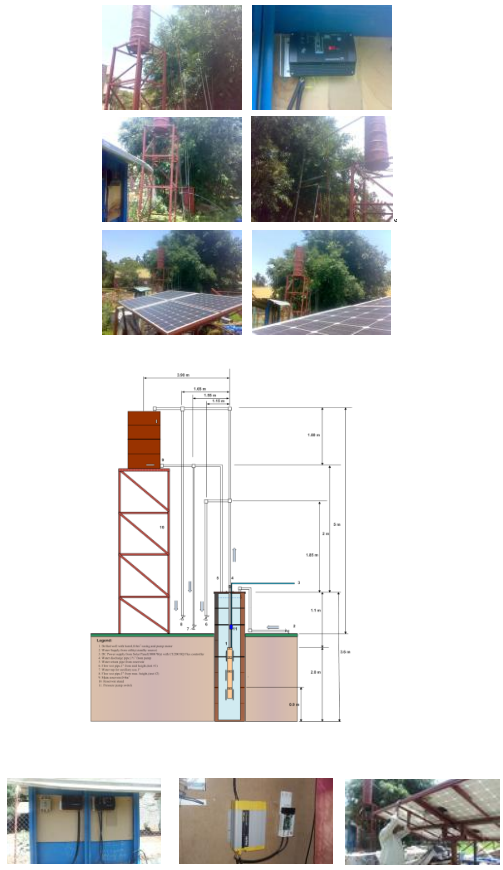

Figure 3: PV (including a manual solar tracker) water pumping model built at BDU

Data collection was performed using this model. A sample of the collected data is presented in Table 1.

#	Date	Time	At fixed Panel tilt angle, β = 22° SF	At adjustable Panel angle towards sun ray	Max. Height in meter	Min. Height in meter	Discharge rate to fill 30 lit.gal	Flow rate [lit/sec]	Power consumption [kW]			
1	8/3/2013	10:50			√		39.47	0.76	0.22			
2		12:06			√		39.52	0.76	0.21			
3		12:55			√		39.47	0.76	0.22			
4	8/5/2013	8:15			√		39.13	0.77	0.22			
5		8:45			√		39.25	0.76	0.23			
6		9:30			√		39.47	0.76	0.22			
7	9/8/2013	12.17		√	√		39.47	0.76				
8		12.19		√	√		34.48	0.87				
9		12:20		√	√		33.42	0.90				
10		12.23		√	√		33.88	0.89				
11		12.25		√	√		39.91	0.75				
12		12.28		√	√		35.49	0.85				
13		12.31	√		√		35.98	0.83	0.22			
14		12.33	√		√		35.07	0.86	0.22			
15		12.34	√		√		35.40	0.85	0.22			
16		12.35	√		√		35.15	0.85	0.22			
17	9/9/2013		√		√		38.10	0.79	0.24			
18		10:10	√		√		38.10	0.79	0.24			
19		10:20		√	√		37.40	0.80	0.23	With flow meter		
20		10:30		√	√		37.90	0.79	0.24	t1	11.86	35.58
21		10:40		√	√		37.90	0.79	0.24	t2	12.76	38.28
22		10:43				√	38.10	0.79	0.2	t3	12.42	37.26
23		11:02				√	38.10	0.79	0.2	t4	12.62	37.86
24										t5	12.59	37.77
25										t6	12.42	37.26
26										aver	12.445	37.335
27										flow rate	0.8035	0.803536
28												

Table 1: Data collected with the BDU-IOT model

3 DESSEMINATION of the MODEL in the rural community

3.1 Scope of the project

The scope of the project was limited to the Central Amhara in the surroundings of the city of Bahir Dar and aims at serving the rural community and as a pilot research site for future expansion

Using as a model, the first ever realized PV and wind based system built at the IOT of BDU, which was operational since October, 2010, the project was scoped to include a few localities around the city of Bahir Dar. They include the Kinbaba and Merawi Worredas as shown in Picture 1.

Picture 1. Kimbala located at 11° 24' 47" N and 37° 24' 7" E; 2127.8 m asl.

The selection of the sites was made based on the following considerations:

- Adequate survey of all Solar and Wind energy-based water development projects, in the central region of the state of Amhara, the larger state in Ethiopia;
- Identification of water spots near Bahir dar;
- Size of the water catchments at lower and upper levels;
- Estimation of material, construction and installation costs;
- Installation operation; and
- Performance Evaluation

3.2 Project timeline

The project timeline was drafted as in Table 2.

No.	Phases	Activities to be Supported	Unit	Qty	Unit Cost	Total Cost (ETH Birr)	Remark
1	Phase 1 In June 2013	Identification of water spots (water- sources) which are found at the outskirt of the Bahir Dar town (Worredas) and doing a Community feasibility, Technical Feasibility & Technical Design: a. Preliminary Site visit to select a candidate* village; b. Meeting with officials at University and local kebele administrative levels to create the sense of ownership on the project; c. Determination of spring locations, its elevations** and seasonal water discharge; d. Sizing of the water catchments at lower and upper level reservoirs (delivery point); e. Sizing of the system layout with respect to the population water requirement, topography, yield and its future sustainability; f. Consideration of environmental factors (temperatures; dust; significant wind, shading, hail/storm loading; etc.)	Site	5 Site			BDU,UDC Support and local Adm. officers is required GPS 72H IS available at BahirDar weter supply at worreda Barometer,/ Digital Altimeter or Clinometers is required * *at this stage the criteria is so limited* ** *The Bahir Dar Zuria Worreda water supply adm. Has provided The GPS meter*
2		Conducting a meetings with local Adm. officers of the granted kebele's on logistical considerations : a. Creating awareness on the technological advantages, benefits and the outcomes of the system among the local leaders, villagers and School students; b. Determination/clarification of the contributions and support of the villagers and sponsors before and after the project commencement; c. Signing an agreement/ MoU/ with Worreda and Kebele administrations and BDU.	Site	1 Site			Joint work is required
3		Transport cost for a minimum of six days to observe the recommended sites and visit by BDU staff & local administrators.	Site	6	6x1000	6000	to be covered by IOT,BDU
4		Per diem for team members	Br/d		6x5x300	9000	To be regulated by IOT,BDU
5	Phase 2 July 2013	Construction of the lower Collection chamber/ water catchment **(min. capacity 28m^2, height = 4 metre)** to insert motor pump or rotto	Pcs			50000	
6		4 x BP250 watt solar module	Pcs	4***	6114.717	36688.302	*** System cost is made by $1=18.90 Birr
7		Prosine, Inverter, 1800I-24V	Pcs	1	16810.038	16810.038	
8		60 amp charge controller, MPPT	Pcs	1	8834.049	8834.049	
9		Wireless Vantage Pro2 Plus	Pcs	1	355,423.95	355,423.95	
10		11 SQF 2 Submersible Water Pump	Pcs	1	30,943.08	30,943.08	
11		On/Off Switch Box with status display	Pcs	1	5,248.15	5,248.15	
12		Whisper 200	Pcs	1	2,724.00	2,724.00	
13		Power house and guard room 5x5 m^2	Pcs	1	30000	30000	
14		Construction of the upper reservoir:					
		- Material Cost for 60000 litres masonry reservoir or rotto: Cement, metal bars, grabble, sand, etc.	Pcs	1	140000	140000	
		- Transport (fuel) cost for construction materials	Pcs	1	30000	30000	
		Pipe line connection for both levels: PVC 1-1/4 pipe, joint connectors, line truck under ground, etc. 2000m/6x141birr, and connecting elements 2000/6/2=166 pcs plus more elbows ...man power for digging the pipe line	Pcs	1	70000	70000	
15		Per diem for Contractor for ≈ 2 months	Pcs	1	10000	10000	
16		Labor cost for upper reservoir	Pcs	1	40000	40000	
17	Phase 3 8/1/2013	Structural Supports for PV Panels:4 x BP250 (H x L x W)					
		- Frame and stand assembly which will be suitable for max. power tracking and to its mobility: Welding, assembly and painting, and grounding .. with labor.	Pcs	1	15000	15000	To be managed with mechanical engg. at the campus
		- Embedment depths, and concrete volumes based on the post height and panel array size for a given system.;					
		Fencing 12x12m^2 : wood logs, cement,sand, grable and mesh wires, lock, etc.	Pcs	1	1x10000	10000	To be done at the site.
18		Water distribution points (bono), 3 points	Pcs	3	3x20000	60000	
19		Installation of solar pump and control	Pcs	1	5000	5000	
20		Transport cost for supervision: twice/week for 2 months	trip	16	16x500	8000	
21		Periodical evaluation of its performance after its completion – Transport cost once/month in a year	days	10	10x500	5000	
22		Consumable Items:					
		- Small digital camera	Pcs	1	1x3000	3000	
		- Telephone and internet card	Pcs	12	12x100	12000	
		- Stationary materials for training documents & demo.	Pcs	1	1x5000	5000	
					Sub Total	508000	
					Contigency	10%	
						50800	
					Grand Total	558800	

Table 2: Project timeline

3.3 Sample target areas

The following localities were targeted for survey and assessment for project feasibility:

Baydegim Spring: Constructe by Red Cross Ass. Baydegim River
Spring Location: – 12 62 292..N and 36 0325605.E
Elevation – 2098 m asl.
Yield – Outlet A; 20 l/6.42min = 0.052 l/sec
Outlet B; 20 l/4.30min = 0.0775 l/sec
Total yield = 0.125 l/sec = 0.45 m3/hr = 10.8 m3/day
Population served – 100 hh ≈ 7000 including School students from six Kebeles

Dibdib Spring
Spring Location: – 12 61 143 .N and 37 0325792 .E
Elevation – 2105 m asl.; Top land location(≈ 1 km)* from spring =. 2145.79.m asl.
Yield in dry season: Outlet A; 10 l/1.16min = 0.104 l/sec
Outlet B; 20 l/2.24min = 0.15 l/sec
Total yield = 0.254 l/sec = 0.91 m^3/hr = 21.95 m^3/day
Population served – 90 hh ≈ including students from other Kebeles
Flow rate for the pump = 21.95m^3/day/5.5 peak hour per day = 3.99 m^3/hr = 0.0665 m^3/min= 0.00111 m^3/sec= 1.108 l/sec
Water Storage volume = 21.95 m^3/day x 3 days = 65.85 m^3 + wet season ≈ 80 m^3 - 80 000 litres
Lower catchment volume = 28m^3

Tikurit Spring: Wojji River
Spring Location – 12 61 768 .N and 37 03 27 402 E
Elevation – 2107 m asl.;
Top land location(≈ 900m)* from spring = 2177 m asl.
Yield – Outlet A; 10 l/min = 0.167 l/sec
Total yield = 0.167 l/sec = 0.6 m^3/hr = **14.4 m^3/day**
Population served – 50 hh, including students from other Kebeles

Shileshu Spring, Birgera River
Spring Location – 12 61 217..N and 37 03 24 407 E
Elevation – 2098 m asl.; Top land location(no)* from spring = at the same level
Yield:
Outlet A; 20 l/1.63min = 0.205 l/sec
Outlet B; 20 l/3.1min = 0.108 l/sec
Outlet C; 10 l/1.36min = 0.123 l/sec
Total yield = 0.436 l/sec = 1.6 m^3/hr = 37.7 m^3/day
Population served – 50 hh, including students from other Kebeles
Flow rate for the pump = 37.7 m^3/day/5.5 peak hour per day = 6.9 m^3/hr = 0.114 m^3/min= 0.0019 m^3/sec = 1.9 l/sec
Water Storage volume = 37.7 m^3/day x 3 days = 113.1 m^3

4 PROJECT COST ESTIMATION

No.	Phases	Activities to be Supported	Unit	Qty	Unit Cost	Total Cost (ETH Birr)	Remark
1		Identification of water spots surrounding Bahir dar and doing Community feasibility: a. Preliminary Site visit for selection of a candidate village b. Determination of locations, elevations and water disgarge	Sites	≤ 5			Joint work is required
2	**Phase 1** In March 2013	Sizing of the water catchments at lower and upper level, Technical feasibility	Site	5			Barometer,/ Digital Altimeter or Clinometers
3		Conducting meetings on logistical considerations with local Adm. officers	No.	5			Joint work is required
4		Transport cost for a minimum of six days to observe the recommended sites and visit local administrators.	G/R	6	6x500	3000	to be covered by IOT,BDU
5		Per diem for One Instructor , One EC member and three members	Birr/d		6x5x300	3600	To be regulated by IOT,BDU
6		Construction of the lower catchment					
7		4 x BP250 watt solar module	pcs	4	$323.53	$1,941.18	
8		Prosine, Inverter, 1800I-24V	pcs	1	$889.42	$889.42	
9		60 amp charge controller, MPPT	pcs	1	$467.41	$467.41	
10		Wireless Vantage Pro2 Plus			$995.00	$995.00	
11		11 SQF 2 Submersible Water Pump			$1,637.20	$1,637.20	
12	**Phase 2** April-May 2013	On/Off Switch Box with status display			$277.68	$277.68	
13		Whisper 200			$2,724.00	$2,724.00	
14							To be determined after accomplishing of the phase 1
15		Construction of the upper reservoir					
16							
17							
18		Pipe line connection of both levels					
19		Transport cost					
20		Material Cost: Cement, metal bars, Galvanized water pipe, valves, water taps, water meter, angle iron, Bolt nut PVC water pipe and hand tools					
21		Installation of solar panels and pumps					
22	**Phase 3** June 2013	Water distribution points					
23		Periodical evaluation of its performance					
24		Transport cost					

Table 3: Cost Estimation

5 CURRICULUM DEVELOPMENT

The pursuit of this model renewable energy project at BDU's IOT has sparked further interest in the development of a more comprehensive curriculum on renewable energy. Although the university has a long standing experience in teaching energy courses in its undergraduate and postgraduate programs, the advent of the construction, on its campus, of a PV and wind energy based model has provided a valuable tool to be utilized in energy courses for experimental observations and data collection on the performance of the system. The following courses are currently benefiting greatly from this addition: EENG 7063, Renewable Energy Resources and Technologies; EENG 4165, Energy Conversion and Rural Electrification; and EENG 428, Applied Energy Conversion. These courses provide a strong background to the students in the PV and wind energy technologies and their applications to serving rural communities.

6 AMBULATORY ENERGY DELIVERY SYSTEM

UDC and BDU's IOT are contemplating conceptualizing and building an "ambulatory energy delivery system", which will serve to support the efficient implementation of their water delivery project in rural communities. In fact, in the near future, the BDU team will transport the current PV "manual" tracking system and the submersible water pump and its accessories, to a local community. This effort has the blessing of the President of BDU and will be a good impetus for the dissemination of the project in rural communities. An early version of the conceptual "ambulatory power delivery system", depicted in Fig. 5, includes a set of four 250W solar modules, assembled in a foldable mechanical setting. The set can then be stacked up and carried on a horse-drawn cart or an all-terrain vehicle throughout the communities, and provide power to the water pump for filling up pre-built reservoirs or water containers.

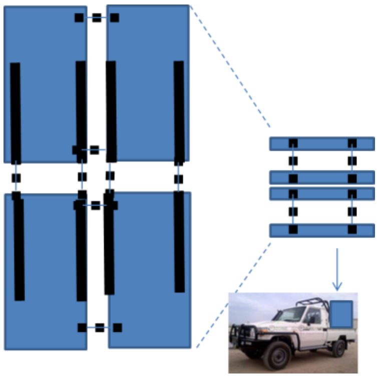

Figure 4: Ambulatory Power Delivery System (concept)

7 CONCLUSION AND ACKLOWLEDGMENTS

The partnership between UDC and BDU's IOT has been very successful and bears promising achievements in the sector of environmentally clean water delivery to rural communities in Ethiopia, deprived of grid power, for energy supply to water pumps. The US Embassy in Ethiopia is to be highly commended for supporting this partnership by providing a seed grant. It is now incumbent primarily on BDU to take the project to the next level by raising local funds to further facilitate its implementation on a larger scale in the state of Amhara as well as throughout the country. UDC will also continue to support BDU in this endeavor.

8 REFERENCES

[1] Press Release, March 2009, US EMBASSY, Addis Ababa, Ethiopia

[2] *Completion of a Model, Low Cost, Novel PV Powered Water Delivery Project in Rural Ethiopia* , S. Lakeou et al, EUPVSEC27