ESTIMATION OF THE AMOUNT OF ELECTRIC ENERGY GENERATABLE PER YEAR USING RAIN ACCUMULATED WATER FROM ABOH AND AHIAZU MBAISE TO DRIVE A HYDRO TURBINE IN FUTO, NIGERIA

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Abstract - Flooding, which is now a yearly occurrence in most parts of the World, can be minimized if reservoirs are constructed at suitable locations to store rain accumulated water for the purpose of irrigation or electric power generation. In that light, we have estimated the amount of electric energy that can be generated using rain accumulated water from Aboh and Ahiazu Mbaise in Imo State, Nigeria to drive a hydro turbine in the Federal University of Technology, Owerri, Nigeria. This was done using the rainfall data of Mbaise, accessed from www.worldweatheronline.com; the land area of Aboh and Ahiazu Mbaise, measured with the help of Google map; and the average altitude difference of FUTO and the reservoir site at Aboh Mbaise, determined with the help of Google topographic map. It was estimated that a total of 9.7 GWh of electricity can be generated per year if 100% of rainwater from Aboh and Ahiazu Mbaise is accumulated and used to drive a hydro turbine in FUTO. This is equivalent to 406 days of 10 MW of electric power. If 30% of the rainwater is accumulated instead, a total of 2.9 GWh of electricity can be generated per year, which is equivalent to 122 days of 10 MW of electric power.

Keywords: flooding, global warming, rainwater, electric power, google map

1. INTRODUCTION

The negative impact of fossil fuels use to human race and the Universe at large has reached alarming levels. This ranges from global warming to the increase in the global morbidity rate as a result of the presence of toxic gases in the atmosphere. Global warming is strongly believed to be caused by the increased levels of greenhouse gases in the atmosphere, of which the carbon monoxide and carbon dioxide released as a byproduct of fossil fuel combustion are the most prominent. Human activities in general since the beginning of the industrial revolution in 1750, to early 2017 have contributed to the increase in the atmospheric carbon dioxide concentration from 280 ppm to 406 ppm [1]. Ballantyne et al. [2] also alluded to this fact by inferring that about 350 billion tons of carbon on the average has been emitted by humans to the atmosphere since 1959.

The World is now conscious of the undesirable consequences of continued use of fossil fuels and different countries are currently making concerted efforts at replacing fossil fuels as energy sources with renewable energy resources. Renewable energy resources include water, solar radiation, wind, etc.

Rain accumulated water power plant is a kind of hydro power plant that is designed and implemented without the use of natural water bodies. It can be implemented with reservoirs designed to be filled by rainwater runoff through artificially constructed water channels. A hydropower plant employs hydro turbine to convert the potential energy of water in an elevated reservoir or the kinetic energy of flowing water to mechanical energy which is in turn transformed to the required form of energy like electricity using an alternator or generator. The utilization of rain accumulated water for electric power generation will help to reduce the negative effects of flooding which is now a yearly occurrence in most parts of the World, as a result of the increased rate of rainfall and melting of ice in Antarctica, believed to be caused by Global Warming.

On the other hand, a solar power plant converts the energy in solar radiation to electricity using photovoltaic modules, solar steam turbines, solar thermoelectric generator, or solar thermionic generator.

Renewable energy resources utilization for power generation has inherent limitations ranging from unpredictable quantities, daily and seasonal variations to deployment issues. For instance, water which is one of the most utilized renewable energy resources has the problem of low water levels in reservoirs during dry seasons. Another prominent renewable energy source is solar. The variation of solar radiation throughout the day and its absence at night is the limiting factor against solar energy utilization.

The use of two or more renewable energy sources in hybrid design for electric power generation has been globally recognized as the best solution to the intermittency problem of renewable energy sources. Many researchers have worked on hybrid power generating systems and many are still working to either improve on the existing ones or create new systems. Nnadi et al. [3] investigated the deployment of hybrid solar-wind energy power plant for remote area electrification in South-Eastern Nigeria. The simulation results of the work revealed the improvement in the power plant reliability factor when designed into a hybrid system as opposed to when the different renewable energy sources were used separately. Other works that produced similar results include Bhandari et al. [4] which reviewed the optimization of hybrid renewable energy power systems; Medugu and Michael [5] which investigated the integrated solar-wind hybrid power generating systems for residential application; Paiva and Carvalho [6] which designed and studied the behavior of integrated hybrid power system based on renewable energy sources (wind and solar) with electric wind MPPT; and Godson et al. [7] which studied solar PV-wind hybrid power generating systems. Machado et al. [8] studied the reduction of renewable energy sources intermittence with seasonal pumped storage plant and concluded that seasonal pumped storage plant could effectively reduce the intermittency of wind and solar sources and thus contribute to the optimization of the Brazilian electricity sector. Ohajianya et al. [9] investigated electric power generation using rain accumulated water and solar energy in hybrid design and concluded that a total of 477.45 kWh of electricity could be generated in a year using rain accumulated water from the rooftop of University of Port Harcourt Nigeria's faculty of Science building which has a roof cover area of 6,236 m^2.

One of the problems limiting the deployment of hydropower plants is lack of suitable sites to construct dams off natural water bodies and realize high enough net head for cost-effective hydropower generation. Another limiting factor is the disruptive ecological effects of constructing large dams off natural water bodies [10]. These factors can be minimized by creating reservoirs off artificially created channels of rainwater run-off.

Again, solar power plants require storage systems to store energy when solar radiation is available and the stored energy will then serve as an energy source when there is low or no solar radiation. Lead acid batteries are mostly used for this purpose but they have the problem of low efficiency and unpredictable durability. Now that hydro turbines and solar water pumps with efficiencies of over 90% exist [11, 12], there is need to adopt pumped storage as a viable means of storing solar energy for electric power generation. The investment payback for some PV water pumped storage systems is found to be 4 to 6 years [13]. This short energy payback period, therefore, presents hydro-solar energy hybrid power plant as a viable power plant that should attract the interest of different countries of the World.

This research focuses on the estimation of the amount of electric energy that can be generated per year using rain accumulated water from Aboh and Ahiazu Mbaise to drive a hydro turbine in the Federal University of Technology Owerri, Nigeria. It is a necessary research that must be carried out before a rain accumulated water (hydro) – solar energy hybrid power plant can be designed. We have articulated two topologies of the rain accumulated water – solar energy hybrid power plant.

1.1. Rain accumulated water – solar energy hybrid power plant topology 1

The block diagrams of rain accumulated water – solar energy hybrid power plant topology 1 is shown in Fig.1.

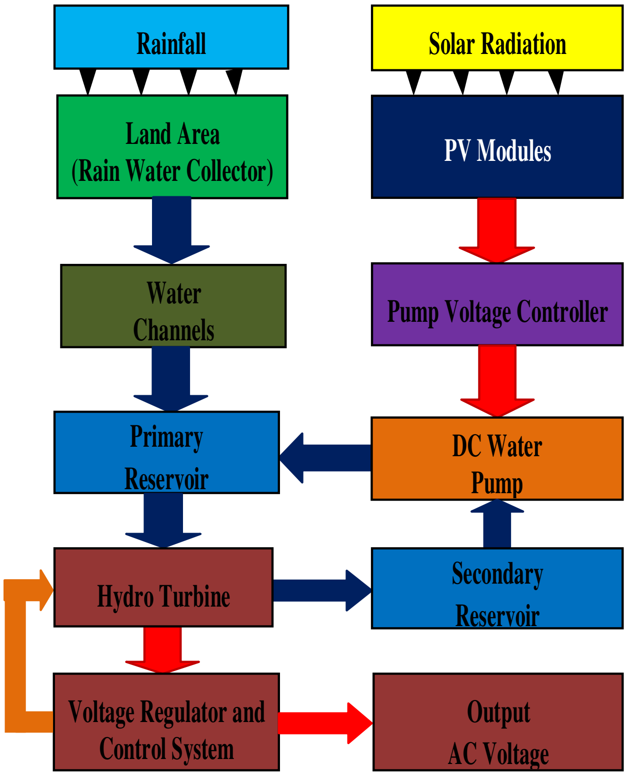

Fig. 1. Block diagram of rain accumulated water-solar energy hybrid power plant topology 1

(= electric current flow, = water flow, = feedback signal)

In this hybrid power plant topology, rainwater in a defined geographical area is collected in a primary reservoir through both natural and artificial drainage systems. The primary reservoir is sited at a suitable location in the area where it can effectively function as the artificial river of a hydrographic basin. The accumulated water is then channeled via pipe to drive a hydro turbine located at a different region of lower elevation. After driving the turbine, the water now flows into a secondary reservoir from where it is pumped back into the primary reservoir by a direct current (dc) water pump powered by a solar power plant. The solar power plant is designed to pump back a certain volume of water in a year, to complement the amount of water needed for the continuous running of the hydro turbine to supply the needed power throughout the year.

1.2. Rain accumulated water – solar energy hybrid power plant topology 2

The block diagrams of rain accumulated water – solar energy hybrid power plant topology 2 is shown in Fig.2.

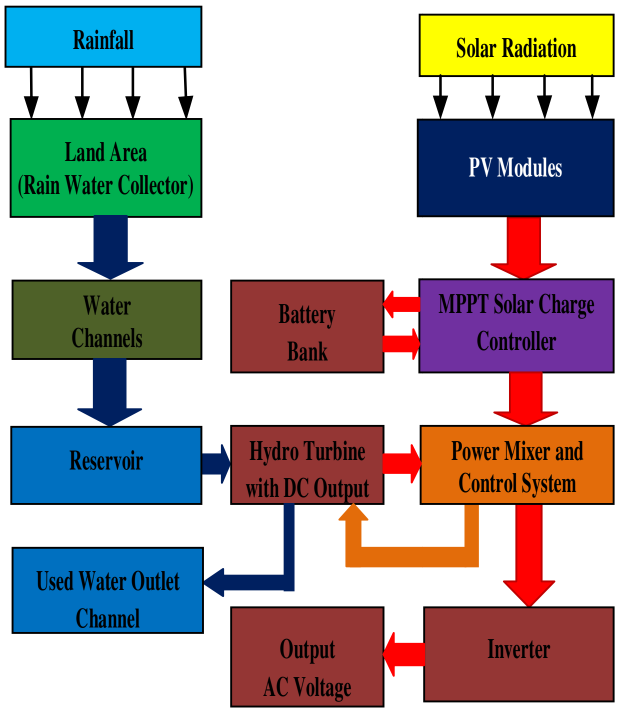

Fig. 2. Block diagram of rain accumulated water-solar energy hybrid power plant topology 2
(= electric current flow, = water flow, = feedback signal)

In the rain accumulated water – solar energy hybrid power plant topology 2, rain water is also accumulated in a reservoir and used to drive a hydro turbine located at a region of lower elevation as described in topology 1. But after driving the turbine, water is discharged through an outlet channel. The direct current (dc) power output of the hydro turbine is connected to the power output of the solar power plant part of the hybrid system in a power mixer and control system. The maximum power point tacking (MPPT) solar charge controller component of the solar power plant ensures that the maximum possible power is drawn from the PV modules at all times. The power mixer and control system compares the needed load power demand and the supplied power from the solar power plant, and now controls the hydro turbine to supply the deficit, so that the hybrid power plant will always deliver the needed power. The solar power plant is designed only after the total amount of electric energy generatable from rain accumulated water in the chosen geographical area is estimated. The estimated rainwater generatable energy will help in determining the size of the solar power plant required for the hybrid power plant to supply the needed power all year round.

2. MATERIALS AND METHODS

The estimation was carried out using a nine years rainfall data of Mbaise, Imo State accessed from worldweatheronline.com as shown in Table 1 (the units are in millimeters).

Table 1. Nine Years Rainfall Data of Mbaise [14]

YR	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
2009	134.18	105.61	216.91	368.12	625.12	597.56	615.78	699.34	839.56	800.16	143.20	7.20
2010	20.01	103.54	104.79	249.05	357.09	509.98	509.56	794.02	845.94	316.67	158.67	33.80
2011	15.96	131.85	107.65	121.85	241.42	331.38	436.60	374.19	656.50	329.56	91.60	11.80
2012	35.41	113.13	77.32	181.38	265.73	370.14	327.29	358.98	394.43	326.01	133.23	27.40
2013	57.00	75.40	156.31	244.02	309.98	343.80	441.59	403.20	482.12	351.81	124.23	74.28
2014	34.62	54.97	150.19	182.84	258.29	287.50	375.01	382.31	464.89	398.32	126.50	15.04
2015	17.21	73.74	114.73	79.72	128.37	179.16	255.77	304.72	265.75	247.65	100.42	3.50
2016	4.20	21.57	166.07	92.06	143.72	170.18	327.38	338.99	234.69	185.46	76.20	12.00
2017	31.10	9.00	50.20	146.80	132.70	165.80	378.60	656.80	491.60	416.00	124.40	14.30
R (mm)	**38.85**	**76.53**	**127.13**	**185.09**	**273.60**	**328.39**	**407.51**	**479.17**	**519.50**	**374.63**	**119.83**	**22.15**

The monthly average of the nine years rainfall data, R (mm) was calculated by summing up each month's rainfall amount over the nine years and dividing the total sum by nine.

The horizontal land area of Aboh and Ahiazu Mbaise, A_h was determined as 299.48 km^2 using the Google Map as shown in Fig. 3.

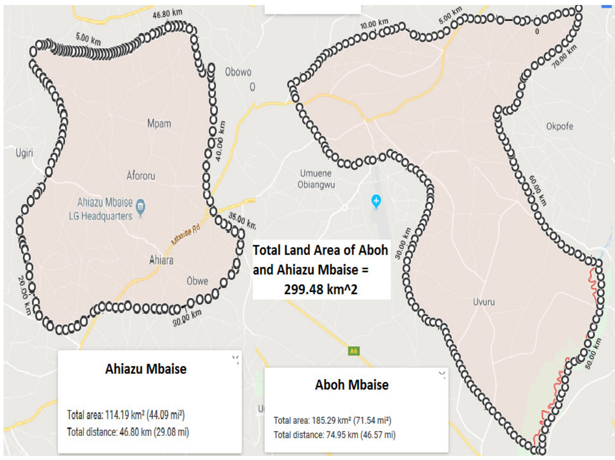

Fig. 3. Map of Aboh and Ahiazu Mbaise for Area Estimation

The average altitude difference between Federal University of Technology Owerri (FUTO) and a selected location for the primary reservoir at Aboh Mbaise, hg was determined as 50 m using the Google Topographic Map. This was followed by the determination of the monthly accumulate-able volume of rain water, V (liters), using the equation:

$$V = RA_h \tag{1}$$

where R (mm) is the average monthly rainfall amount and A_h (m^2) is the total horizontal land area of Aboh and Ahiazu Mbaise. The obtained monthly volume of rainwater in liters was converted to volume in m^3 and recorded. The monthly generatable electric energy from rain accumulated water, E (J) was then calculated using the formula

$$E = \eta_0 \eta_1 \rho g h_g V \tag{2}$$

where η_0 is the Pelton turbine efficiency (90% used), η_1 is the water transmission efficiency (90% used), ρ is the density of water (= 1000 kgm^{-3}), g is the acceleration due to gravity (= 9.8 ms^{-2}), h_g is the gross head (= 50 m), and V is the accumulate-able volume of rainwater. The period of time in hours and days to draw 10 MW of electric power from the monthly generatable energy were also determined and recorded. The results were tabulated. The estimation was repeated using 30% of the accumulate-able volume of rainwater. The results were also tabulated.

3. RESULTS AND DISCUSSION

The average monthly electric energy that can be generated using rain accumulated water from Aboh and Ahiazu Mbaise to drive a hydro turbine in FUTO was estimated as presented in Table 2 (when 100% of rainwater is accumulated) and Table 3 (when 30% of rainwater is accumulated). A bar chart of the monthly generatable electric energy from January to December is presented in Fig. 4. Another bar chart shown in Fig. 5 was drawn to show the number of days in each month to draw 10 MW of electric power from the accumulate-able rainwater.

Table 2. Result of Rainwater Electric Energy Estimation when 100% of rainwater is accumulated

	Average Rainfall, R (mm)	Accumulate-able Water, V(m^3)	Generat-able Energy, E (MJ)	Generat-able Energy, E(MWh)	Time to Deliver 10 MW, T (h)	No. of Days to Deliver 10 MW D(days)
Jan.	38.85	11,634,798	4,617,851	1,283	128.3	5.3
Feb.	76.53	22,919,204	9,096,632	2,527	252.7	10.5
Mar.	127.13	38,072,892	15,111,131	4,198	419.8	17.5
Apr.	185.09	55,430,753	22,000,466	6,111	611.1	25.5
May	273.60	38,072,892	32,521,084	9,034	903.4	37.6
Jun.	328.39	98,346,237	39,033,622	10,843	1,084.3	45.2
Jul.	407.51	122,041,095	48,438,111	13,455	1,345.5	56.1
Aug.	479.17	143,501,832	56,955,877	15,821	1,582.1	65.9
Sep.	519.50	155,579,860	61,749,646	17,153	1,715.3	71.5
Oct.	374.63	112,194,192	44,529,875	12,369	1,236.9	51.5
Nov.	119.83	35,886,688	14,243,427	3,957	395.7	16.5
Dec.	22.15	6,633,482	2,632,829	731	73.1	3.0
Tot.		884,178,762	350,930,551	97,481	9,748.1	406.2

Table 3. Result of Rainwater Electric Energy Estimation when 30% of rainwater is accumulated

	Average Rainfall, R (mm)	30% of Accumulate-able Water, V(m^3)	Generat-able Energy, E (MJ)	Generat-able Energy, E(MWh)	Time to Deliver 10 MW, T (h)	No. of Days to Deliver 10 MW D(days)
Jan.	38.85	3,490,439	1,385,355	385	38.5	1.6
Feb.	76.53	6,875,761	2,728,990	758	75.8	3.2
Mar.	127.13	11,421,868	4,533,339	1,259	125.9	5.2
Apr.	185.09	16,629,226	6,600,140	1,833	183.3	7.6
May	273.60	24,581,318	9,756,325	2,710	271.0	11.3
Jun.	328.39	29,503,871	11,710,086	3,253	325.3	13.6
Jul.	407.51	36,612,328	14,531,433	4,037	403.7	16.8
Aug.	479.17	43,050,549	17,086,763	4,746	474.6	19.8
Sep.	519.50	46,673,958	18,524,894	5,146	514.6	21.4
Oct.	374.63	33,658,258	13,358,962	3,711	371.1	15.5
Nov.	119.83	10,766,007	4,273,028	1,187	118.7	4.9
Dec.	22.15	1,990,045	789,849	219	21.9	0.9
Tot.		265,253,629	105,279,165	29,244	2,924.4	121.9

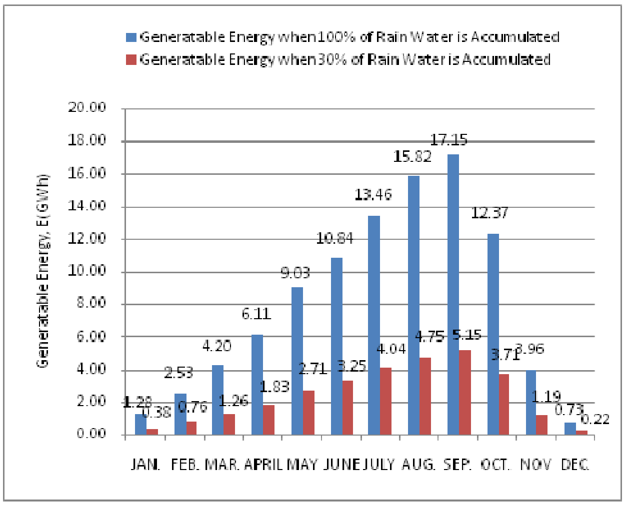

Fig. 4. Bar Chart of Monthly Generatable Electric Energy

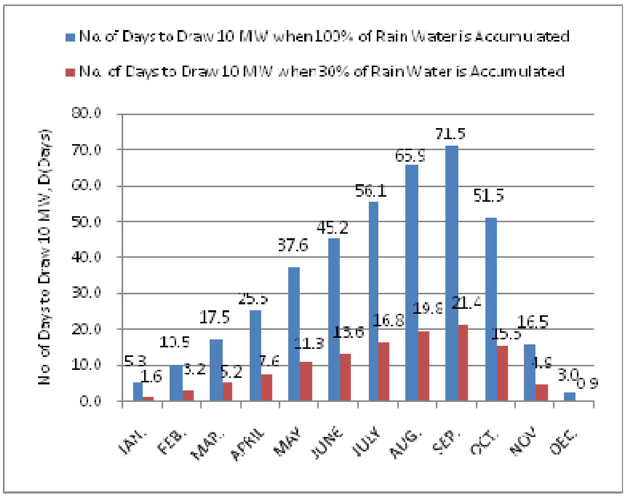

Fig. 5. Bar Chart of No. of Days to Draw 10 MW from the Accumulated Rain Water

It can be seen from Tables 2 and 3 that a total of 97.48 GWh of electricity can be generated from the rain accumulated water in a year if 100% of the rainwater from Aboh and Ahiazu Mbaise is accumulated. While it is not possible to accumulate a 100% of the rainwater in a given area, it is quite possible to accumulate 30% of the total rainwater in an area. 30% of 97.48 GWh is 29.24 GWh which is still a huge amount of electric energy. 29.24 GWh of electricity is worth over two hundred and fifty million US dollars in Nigeria (with average grid electricity price of nine cents per kWh). One can also deduce from this work that if 30% of the total rainwater in a year from Aboh and Ahiazu Mbaise is accumulated and used to drive a hydro power plant in FUTO that can generate and supply 10 MW of electricity, it will deliver electricity for approximately 122 days at full load capacity.

From Fig. 4, it can be seen that the month to generate the highest amount of electric energy from rain accumulated water is September, with a generatable amount of electric energy of 17.15 GWh (with 100% of the accumulate-able rainwater) or 5.15 GWh (with 30% of the accumulate-able rainwater).

For the power plant to deliver 10 MW of electric power all year round, it has to be designed into a hybrid system with solar power plant using any of the two topologies presented in Fig. 1 and Fig. 2. With the hydro turbine capable of generating 10 MW of electric power for 122 days when 30% of rainwater is accumulated (that is 29.24 GWh of electric energy), the solar power plant should be able to deliver 10 MW of electric power for 243 days (that is 58.32 GWh of electric energy). A combination of the two will now work together in a hybrid system to generate and deliver 10 MW of electric power all year round.

4. CONCLUSION AND RECOMMENDATION

A total of 97.48 GWh of electricity can be generated per year if 100% of rainwater from Aboh and Ahiazu Mbaise is accumulated and used to drive a hydro turbine in FUTO. If 30% of the rainwater is accumulated instead, a total of 29.24 GWh of electricity can be generated per year.

If the system is designed to deliver 10 MW of electric power, the 97.48 GWh will correspond to 406 days of 10 MW of electric power while the 29.24 GWh will correspond to 122 days of 10 MW of electric power.

The month with the highest generatable electric energy from Aboh and Ahiazu Mbaise's rain accumulated water is September with a generatable electric energy of 17.15 GWh (when 100% of rainwater is accumulated) or 5.15 GWh (when 30% of rainwater is accumulated) while the month with the lowest generatable electric energy from rain accumulated water is December with a generatable electric energy of 0.73 GWh (when 100% of rainwater is accumulated) or 0.22 GWh (when 30% of rainwater is accumulated).

We hereby recommend that the Government of Nigeria and other countries of the World where flooding has become a yearly tragedy, should consider the option of constructing reservoirs to store rainwater for the purpose of electric power generation. This will help in solving the problem of flooding and inadequate electric power supply.

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