Feasibility of Rainwater Harvesting in High rise Building for Power Generation

Shaleen Martin#1, K. K. Shrivastava#2
[1]PG scholar, Gyan Ganga Institute of Technology & Science Jabalpur
[2]Professor, Gyan Ganga Institute of Technology & Science Jabalpur

***ABSTRACT*- Water is as important for survival of human being as much as food, air etc, but hardly any attention is paid for its economical use and conservation of this precious resource for domestic power generation through Roof top Rain water harvesting. However, in this work an attempt will be made to examine the feasibility of designing a micro hydel power generation utilizing the harvested rain water for a multi storey tall buildings by design a storage system for storing of the harvested rain water at the top storey of the building and another as the underground storage tank for collecting the water after power generation for other uses. The design of storage tanks, pipe network and flow control valves etc. will be done for the optimum utilization of the harvested rain water. The rainfall data of Jaisalmar (desert) and Meghalaya(wettest place) is been collected from the literature and based on the data a relationship between head (H), discharge (Q) and Power(P) is established.**

Keywords-Rain Water Harvesting, Power Generation, Multi-Storey Building.

I. INTRODUCTION

Water harvesting in its broadest sense can be defined as the “collection of runoff for its productive use”. Runoff may be harvested from roofs and ground surfaces. Water harvesting techniques which harvest the runoff from roofs or ground surfaces fall under the term: Rainwater Harvesting, whereas all systems which collect discharges from the water courses are grouped under the term: Floodwater Harvesting. Rainwater harvesting (RWH) primarily consists of the collection, storage and subsequent use of captured rainwater as a supplementary source of water. Both potable and non-potable applications are possible. Examples exist of systems that provide water for domestic, commercial, institutional and industrial purposes as well as agriculture, livestock, groundwater recharge, flood control, process water and as an emergency supply for fire fighting.

Different modes of Rain Water Harvesting

The storage of rain water on surface is a traditional technique and the structures used were underground tanks, ponds, check dams, weirs etc. Recharge to ground water is a new concept of rain water harvesting. The techniques of rain water harvestings can be classified as

- Roof top rain water harvesting system
- Surface runoff rain water harvesting system

POTENTIAL ENERGY OF WATER: Mass that has been raised above the Earth's surface has a potential energy relative to the same mass on the Earth's surface. Running elevated water over a turbine, some of this potential energy can be converted into kinetic and electrical energy. In the water cycle, water evaporates via solar energy and gains potential energy that is then lost again when the water precipitates. This cycle of evaporation, rain, turbine, provides a mechanism for the conversion of solar into electrical energy. At best, the amount of electrical energy that can be generated is equal to the potential energy of the rain. This gravitational potential energy is simply equal to the product of mass, height, and gravitational constant (9.81 m/s2).

RAIN KINETIC ENERGY: Trapping rain, storing it, and running it past a turbine is one mechanism of converting the energy of rainfall into electricity. Another option is to capture the kinetic energy of the rain directly using piezoelectricity, where crystals convert mechanical motion into electricity. Again making the unrealistic assumption of perfect conversion, the amount of kinetic energy in an object is half the mass times the velocity squared. The velocity of rain is limited by air resistance and typically has a maximum of around 8 m/s [1].Recent research has demonstrated how this effect can power small sensors that use only a little amount of energy and are inconvenient to power by other means [2-4].

Rooftop hydroelectric generation, can be designed with a continuous loop of water cycle, is a perpetual energy source that will meet the future of unlimited demands for a populated community.RWH systems were used predominantly in areas lacking alternative forms of water supply. Some researchers also indicated that the wide-spread implementation of RWHSs has been slow, because:

1. The current methods of assessment tend to be simplistic, using generalized rather than site-specific data.

2. The system that addresses spatial factor has not been properly established.

The need for adopting rain water harvesting is–

1. Utilization of the roofs of high-rise buildings.
2. Implementing of this system in a 10-15 storey building, diverted roof top water to the Underground reservoir can be used only for flushing.
3. It provides water at the point of consumption, and family members have full control of their own systems.
4. Providing wireless electricity in a planned community and independent from the problems linked with power plants.

The concept of RWH is both simple and ancient and systems can vary from small and basic, such as the attachment of a water butt to a rainwater downspout, to large and complex, and with also providing wireless electricity in a planned community and independent from the problems linked with power plants like during typhoon seasons of uprooted poles and dislodged wires. For the duration of dry seasons or non rainy days, vacuumed pumped from stockpiled rainwater in tankers on ground level can produce electricity. Rooftop Hydroelectric Generation is the scheme of rainwater channels on the roof of buildings for carrying away water to turbines coupled to a generator that will convert the falling or running water into electricity with the water eventually flowing to tankers to be stockpiled and vacuum pumped back to the roof during non rainy days, instead of pipes carrying water to the sewage as shown in fig(1), with the excess stockpiled rainwater to be used to irrigate plants and gardens.

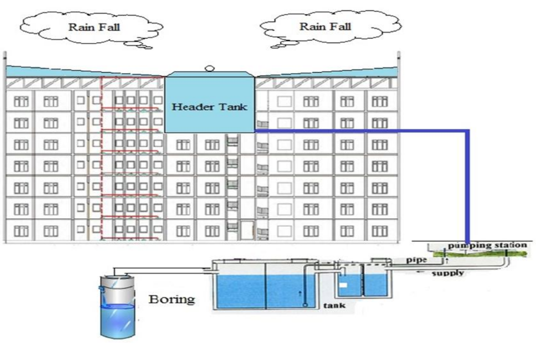


Fig 1.Schematic showing range of common RWH system component

The multi storey building, depends on the square area of the rooftops and gravitational flow of the rainwater, will be classified as small to mini or micro hydro in capacity of providing the energy. The amount of energy that will be produced will be reliant on two things:

The Flow of the Water OR Discharge: The flow of water is simply the quantity of water flowing in the water source.

The Head : Head refers to the pressure at which the water hits the turbine blades, and is the vertical distance from the water source to the generator.

Rainwater Harvesting Potential (Supply) – An analysis will be conducted to generate useful amounts of power for a multi storey building ,both from the available head and the flow-rate, necessary in determining power using volumes of water having the following basic equations like:

$$P = Q \cdot H \cdot \rho \cdot g$$

Where,

Pmax	=	power
Q	=	volumetric flow-rate
H	=	gross head
ρ	=	density of water
g	=	gravitational constant

RWH Potential (m^3) = Rainfall (m) X Catchment Area (m^2) X Collection Efficiency

The power equation is modified by an efficiency factor (η):

$$P = Q \times H \times g \times \rho \times (\eta)\ \textit{effective}$$

This equation provides a reasonable estimate of the power output of a hydroelectric system regardless of its size or construction. Dams serve the continuity of flow while increasing the head of water available to drive the turbines. A small volume of water through high head equal to a large volume through a low head. Direct Rainfall cannot be fully utilized therefore its full utilization can be done by using an Underground reservoir so as to have control over the discharge(flow rate) and also low Head is the lagging factor for the utilization of generating electricity and it is a defeating factor in the power equation when relying on rooftop rainwater collection system. To alleviate the above problems to the least extent and to develop mobilized, sustainable system basically, the main strategies that can be found in the literature to cope with the head variation effect can be summarized as follows:

1. To consider a constant average net head [5].

2. To build an approximation of 'the truthful input-output surface by meshing and triangulation [6].

3. To implement an iterative procedure where each iteration considers a fixed head, which is successively updated [7,8].

4. To make a very realistic and detailed modeling of the problem and apply computer simulation techniques to find a near optimum solution.

This paper has been organized as follows:

1. First of all, the problem description and the model overview where the iterative procedure is explained.
2. The mathematical formulation of the optimization problem solved each iteration is presented.
3. After that a real application of the proposed strategy will be presented in our expected outcome section.

From literature only 3 cents worth of electricity is useful from a single storey building. So, if we increase flows to a usable rate hopefully we will get increased viable energy production. Henceforth by using some technique for iterative solution of non linear equations will be calculated for a multi storey building, for example a community project.

Rainfall – data on rainfall periodicity and durations measured in meters.

Catchment Area – estimated surface areas and options available for RWH, measured in m².

Collection Efficiency – data estimating the runoff coefficient for a given catchment surface.

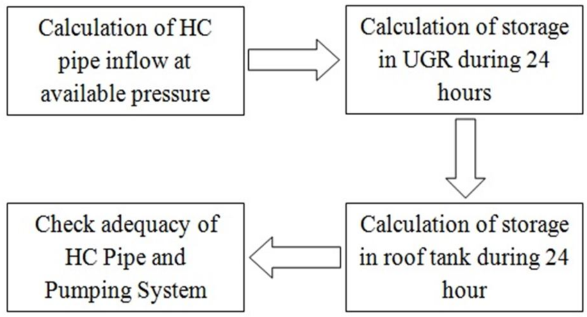
Head- estimated vertical distance from roof top to the generator in meters.

Potential of harvested rain water (Qmax/Qmin) measured in cubic meters.

Calculated Power for a particular(mm) of a state in India in KW.

Depending upon power generated it can be concluded that the system is suitable for Mini/Micro/Power Generation

Pipe network- It is assumed that capacity of UGR is twice as that of roof tank. Flow and head loss in the pipe network will be calculated using Hazen-Williams formulae. Available minimum pressure is assumed to be constant throughout a complete cycle and it will discharge water to UGR at atmospheric pressure through the pipe. The whole analyses follow the flow chart as shown below.



Using Bernoulli's Energy Equation and Hazen William formula only flow in HC pipe will be studied. Again the UGR and roof tank storage behavior depending upon demand and pumping schedule depending upon the assumed HC pipe diameter will be studied.

$$Z_1 + \frac{P_1}{Y} + \frac{V_2}{2g} = Z_2 + \frac{P_2}{Y} + \frac{V_2}{2g} + h_L$$

$$h_L = \frac{10.65 \times Q^{1352} \times L}{Q^{1352} \times D^{637}}$$

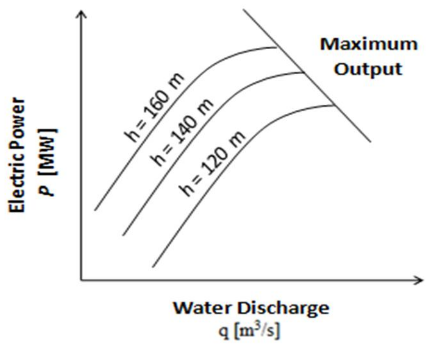
II. GENERATION MODEL OVERVIEW

Hydro Scheduling Problem (HSP) description

In order to compute the production of the hydro chain it is necessary to express accurately the hydroelectric generation functions for the pumping station. This can be attained introducing in the HSP the following equations:

$$P_{ik} = \phi_i(q_{ik}, h_{ik})$$

Where h_{ik} is hydraulic head, and h_{ik} is constant.



Fig(2) Simplified Hydro Scheduling Problem (SHSP)

For Fig (2), we could build the following time-varying functions where the net head dependence has been removed by replacing the equations in (1) by the following ones,

$$p_{ik} = \phi_{ik}^{\upsilon}(q_{ik})$$

This simplified problem will be denoted as SHSP (Simplified Hydro Scheduling Problem). It is important to note that the SHSP requires less computational effort to be solved than the HSP , the unit is treated as non-head dependent.

In this case, the optimal power generation p^{*}_{ik} , must satisfy:

$$P_{ik}^{*} = \phi_i(q_{ik}^{*}, h_{ik}^{*})$$

Thus, functions $\emptyset_{ik}^{\upsilon}(.)$leading to equivalence between HSP and SHSP are the following ones:

$$\phi_{ik}^{\upsilon}(q_{ik}) = \phi_i(q_{ik,} h_{ik}^{*})$$

As the net heads are variables of the problem, univocally related to the reservoir levels at each time period, it is impossible to determine a priori the optimal evolution of net head values (h^{*}_{ik}) , For that reason, the following under-relaxed iterative procedure is proposed

Under-relaxed iterative procedure for a multi storey building

The proposed iterative procedure consists of the following steps :

Step 1) Iteration counter $U = 1$. Initialize h^{u}_{ik}.

Step 2) Build $\emptyset^{u}_{ik}(q_{ik})$.

Step 3) Solve SHSP with $p_{ik} = \emptyset^{u}_{ik}(q_{ik})$,

Step 4) Update h^{u}_{ik}: . If convergence has not been reached, increase the iteration counter, (u=u+l) and go to Step2.

A detailed description of each step is presented here after.

Step1). Assuming an average height of the building, the net head, h [m], can be expressed simply as a function of the roof top catchment area,v[Hm^3].

$$h_i = P_i(\,V_i)$$

In order to initialize h^{u}_{ik} propose to apply the above equation, assuming a linear trajectory of the stored water by joining the initial and the final stored water, i.e. v_i^o and v_i^f , along the temporal scope.

Step2). Functions $\emptyset_{ik}^{\upsilon} = (q_{ik})$ are built by applying (2) to the current values h^{u}_{ik}:

Step3). Once the pumping units have been characterized by their time-varying input-output functions, the SHSP solution can he obtained by solving the medium-scale MILP optimization problem.

In order to model the truthful input-output curve for a given net head of different places of a multi storey building, a piece-wise linear approximation is implemented in the example shown in figure 3, two linear segments are used joining the minimum and maximum discharge points with the maximum efficiency power-outflow point

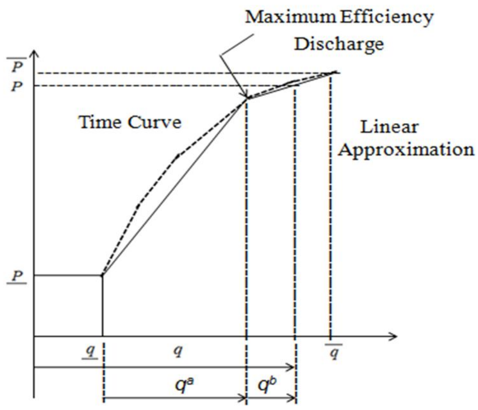


Fig (3) Input-Output Approximation

However, it is necessary to introduce in the SHSP some binary variables in order to model the discrete unit commitment, start-up and shutdown decisions. In this case, when the unit is off (i.e. $U = 0$), the water flow and the power produced must be zero. On the other hand, when the unit is on (i.e. $U = I$), the unit has to discharge at least the minimum output flow q, which is related to the minimum output power p. Therefore, the total water discharge can be expressed as the unit-commitment decision multiplied by q, plus the water discharge over the minimum output flow: $q = U.\,q + q^a + q^b$

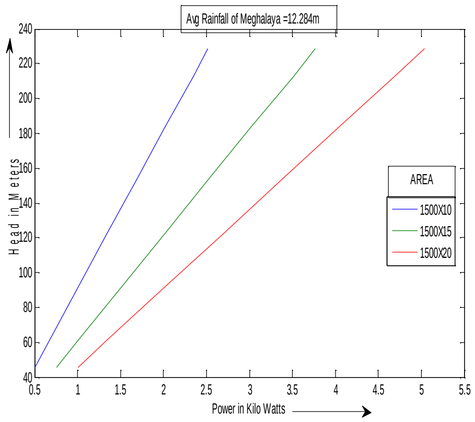
Step4). The aim of this step is to check whether the convergence has been reached or .not, and .in this case, to prepare the input-data for the next iteration v +1.

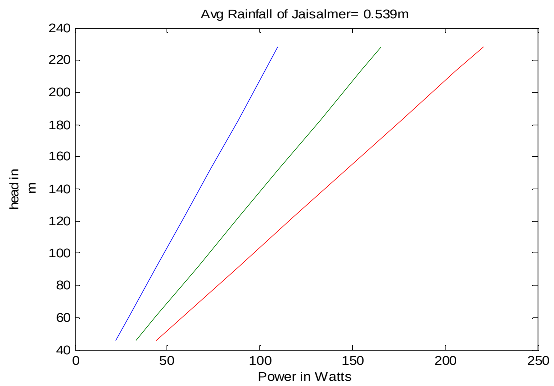
The last solution of the, SHSP provides new values for the reservoir levels v_{ik} and therefore by these values could be used directly to update h_{ik}^{v+1}

$$h_{ik}^{\upsilon+1} = \rho_i(V_{ik})$$

III. RESULT

Assuming maximum consumption onto the single rooftop area 1500 sq feet and 10 feet per floor, the total amount of power generated for AREA (A_1) – 1500 SQUARE FEET, (A_2) – 1500 SQUARE FEET and (A_3) – 1500 SQUARE FEET will get consumed from the harvested rain water having net assumed constant head (obviously for high rise buildings) and 80% of rainfall takes place during 4 months and 20% for rest of the 8 months for Meghalaya and Jaisalmar.Run-off coefficient for concrete pavement=0.85. Hence graph can be plotted between head and power.





IV. CONCLUSION

On the basis of the study conducted, to fill the potential energy tank on top the community people does not have to directly run the water pump during non rainy days and power can be generated from RWH(roof top) as shown in table (1). Hence Meghalaya generates power of 5KW for a micro power generation.

TABLE 1
CALCULATION OF AVERAGE POWER

HEAD IN FEET	AVERAGE POWER IN WATTS (W)					
	JAISALMER (DESERTED PLACE)			MEGHALAYA(WETTEST PLACE)		
	AREA (A_1)	AREA (A_2)	AREA (A_3)	AREA (A_1)	AREA (A_2)	AREA (A_3)
15 x 10	22.09	33.15	44.18	503.68	753.502	1006.9
20 x 10	29.46	44.19	58.9	671.57	1004.67	1342.55
30 x 10	44.19	66.29	88.36	1007.36	1507.00	2013.8
40 x 10	58.96	88.39	117.81	1343.15	2009.34	2685.09
50 x 10	73.65	110.48	147.26	1678.93	2511.67	3356.37
60 x 10	88.38	132.58	176.71	2014.72	3014.01	4027.6
75 x10	110	165.73	220.89	2518.4	3767.51	5034.6

V. REFERENCES

[1] R. Gunn and G. D. Kinzer, "The Terminal Velocity of Fall for Water Droplets in Stagnant Air," J.Atmosph. Sci. 6, 243 (1949).

[2] P. F. Krause and K. L. Flood "Weather And Climate Extremes," US Army Corps of Engineers, Technical Report TEC-0099, September 1997.

[3] R. Farnsworth and E. Thompson, "Mean Monthly, Seasonal, and Annual Pan Evaporation for the United States," U.S. national Oceanic and Atmospheric Administration, NOAA Technical Report NWS 34, December 1982.

[4] L. Ortolano and K. Kao Cushing, "Grand Coulee Dam and the Columbia Basin Project, USA," World Commission on Dams, November 2000.

[5] G. W. Chang, I. *G*. Waight, I. Medinq M. Aganagic, S. Reeves T. Burton, and M. Christoforidis "Experiences With Mixed Integer Linear Programming Based Approaches on Short-Tam Hydro Scheduling," *IEEE* Transaction on power systems,vol.16, pp. 743-749,2001.

[6] J. Garcia-Gonz Ycz and G. A. Castro, "Short-term hydro scheduling with cascaded and head-dependent reservoirs based on mixed-integer linear programming," presented at IEEE Power Tech. Conference, Porto, 2001.

[7] J Medina, A J Conejo. F P Thoden, and J G d Santo. "Medium- term hydro-thermal coordination via hydro and thermal decomposition," Sociedad Espanola de Erladisllca e Investigation operation, vol. 2, pp. 133-150, 1994.

[8] M. Percira and L. Pinto, "Application of decomposition techniques to the Mid-Short-Term scheduling of hydrothermal systems," IEEE Transaction on power systems,vol.PAS-101, pp. 3611-3618, 1983.