

Hydro Power Potential of Low Head Irrigation Reservoirs : A Case Study of Rajasthan

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ABSTRACT

In the present study, hydro power potential of irrigation reservoirs located in Rajasthan (India) is assessed. Low head (range from 4 - 10 m) and very low head (range from 2 to 4 m) turbines, both are used to harness the hydro power from canal head regulators (CHR) of large reservoirs and flowing rivers. They are either impulse (Cross flow turbine, CFT) or reaction turbine (bulb turbines or axial flow turbines). 25 reservoirs are selected on the basis of their volume, head and probability of getting inflow for assessing the hydro power potential by using such type of turbines. Total storage capacity of these reservoirs is 1629 MCM. The hydro power potential is 21.26 and 21.37 million kWh for top 75 and 50% of the total volume and water level corresponding to the 25 and 50% of the volume. It increases up to 31.33 and 25.03 million kWh, when average water level is used for top 75 and 50% of the total volume. Varying head, inter annual variability in available water, short duration of operation and need for civil works at head regulators are the major challenges in installing turbines at these reservoirs. However, the design of portable turbine that can be used both on check dams of small rivers during monsoon and at canal heads of the reservoirs during winter, will make this option feasible and economical.

Keywords : Renewable Energy, Hydro power, Low head turbines, Canal head regulators, Bulb turbines

1. INTRODUCTION

Rapid increase in concentration of greenhouse gases is one of the biggest challenge for human beings in the present time. Hence, even a small effort to generate energy from clean and renewable resources is appreciable. Hydro power is one of the oldest and most commonly used renewable energy source in the world. India is also blessed by nature in form of sufficient rainfall, sloppy mountains and large rivers, which is favourable for generating the hydro power. Although, there is no uniform classification standards worldwide to classify the hydropower plants, they are broadly classified as as presented in Table 1[1]. The total hydroelectric power potential in India is assessed at about 150000 and 15384 MW, from large and small hydro power projects, respectively [1].

Table 1 : Classification of Hydropower plants

Pico	5 kW & below
Micro	100 kW & below
Mini	2000 kW & below
Small	25000 kW & below
Medium	1,00,000 kW & below
Large	above 1,00,000 kW

In last few years researchers also attempted the design of mini, micro and pico turbines for low head (LH) (range

4 -10 m) and very low head (VLH) (range 2 – 4 m) on barrages, perineal canals and river streams [2, 3, 4]. Broadly these turbines are classified as impulse turbine (CFT) or reaction turbines (bulb turbines or axial flow turbines). However, as per the author's knowledge, in none of the study, these turbines are used at the CHR of low head irrigation reservoirs. Hence, in the present study, the hydro power potential of low head reservoirs is assessed for an Indian state Rajasthan. The results of the present study can be extended to other states in India.

2. LOW HEAD (LH) AND VERY LOW HEAD (VLH) TURBINES

Various types of turbines are developed for generating energy from low head ROR, running rivers without any storage (undershoot water wheel; water free vortex turbine), canals, waves, pipe lines etc. These LH and VLH turbines are generally used for head between few of meters to 20 m. However, in the present study only LH and VLH turbines, which are suitable for generating power from irrigation reservoirs are considered. As per the literature review, either cross flow or bulb turbine is suitable for the present cases[5].

The efficiency of cross flow turbines depends on many factors including outer diameter & breadth of runner, number of blades, spacing of blades in the runner, radius of blades curvature, angle of attack, thickness of water jet, the

blade exit angle for first stage and angle between relative velocity of entering water jet and turbine outer periphery[5]. They studied the variation of efficiency and runner speed with different angle of attack, nozzle tip elevation and nozzle tip distance from runner. Adhikari and Wood (2018) [3] also summarized the design of high efficiency crossflow hydro turbines. They only considered the studies which report the efficiency in the range of 80-90%. The limitation of this turbine is that it requires a jet and free space in the downstream. This turbine can be used on CHR, either with slide modifications or install on vertical axis.



Fig. 1 : Cross flow turbine

(Source : https://en.wikipedia.org/wiki/Cross-flow_turbine#/media/File:Ossberger_turbine.jpg)

For ultra-low head applications (head between 4 – 15 m), bulb turbine is one of the most favourable option [6]. Bulb turbine is an axial flow turbine in which a bulb shape body accommodate generator, runner and set of inlet guide vanes inside it [4]. Shandilya et al. (2019) [4] designed the bulb turbine (CFD analysis, ANSYS CFX) without the guide vanes and tested it for power production of 10 kW under the head of 4 m and flow rate of $0.27\text{m}^3/\text{s}$.

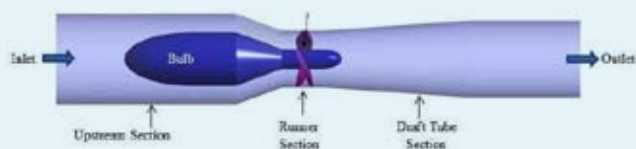


Fig. 2 : Schematic diagram of bulb turbine [4]

CFD software Fluent was used to design the hydro turbine suitable at the lower Mae Ping Dam in Thailand [2]. They also took in consideration the several constraints i.e. the existing civil structure of the dam, the flow regulation for irrigation and limitation of water level. These turbines are more suitable for installation at canal head regulators.

For both type of turbines, the varying head is the major challenge.

3. CASE STUDY AREA

In the present study, Rajasthan state is selected for assessment of hydro power from canal head regulators of low head irrigation reservoirs. Rajasthan, the largest state of India, is located in the western part of the country. The state is divided into 33 districts (Fig. 3). Monsoon rainfall occurs during July

to September, is the only source of water for the state. There is high spatial variation in rainfall and it varies from 900 mm on the eastern part to 120 mm in the western part of the state. Due to the rainfall pattern and topography, it is not suitable to install large hydro power projects in the state. Water stored in the reservoirs during monsoon is one of the major source for irrigation and municipal purposes. The number of reservoirs having capacity more than 1 MCM and total storage volume of the each category of reservoirs is presented in Table 2. There are 3 large reservoirs having capacity more than 1000 MCM name Rana Pratap Sagar, Mahi Bajaj Sagar and Bisalpur Dam. Including Rana Pratap Sagar (172 MW) and Mahi Bajaj Sagar (140 MW), hydro power production facility is installed at Jawahar Sagar Dam (99 MW).

Table 2 : Number of reservoirs with Capacity more than 1 MCM

Sl. No.	Capacity	Number of Reservoirs	Storage capacity (MCM)
1.	More than 1000 MCM	3	4495
2.	416 – 1000 MCM	Nil	
3.	100 – 415 MCM	8*	1402
4.	25 & less than 100 MCM	52	2345
5.	4.25 & less than 25 MCM	211	1908
6.	More than 1 MCM & Less than 4.25 MCM	654	1294
	Total	928	11,444

* Including Kota Barrage

In states like Rajasthan, reservoirs don't have the hydro power production facility due to the water availability for short duration and low heads. However, with the advancement of technology to integrate the power from various resources, it is beneficial to generate power from any type of renewable source. In the present study, the hydro power potential of LH or VLH turbines on the canal head regulators of irrigation



Fig. 3 : District map of Rajasthan

reservoirs is assessed. At some of the locations these decentralized power plants with solar photo voltaic, will provide a more stable grid during winter time, when there is low availability from solar photovoltaic plants.

4. TYPES OF CANAL OUTLETS

Various type of canal outlets are presented in Fig. 4. In old stone masonry dams, pipe or tunnel type canal outlet were constructed. In recent dams, a well type canal outlet



(a) Tunnel type Outlet at Chaparwada Dam (Available head 4 m)



(b) Pipe type outlet at Tordi Sagar Dam (Available head 10 m)



(c) Well type outlet Mashri Dam (Available head 4 m)



(d) CHR of RMC of Bisalpur Dam (Available head 6 m)

Fig. 4 : Canal outlets

is constructed, in which sets of gates are provided on the upstream side and inside the well as shown in Fig. 4 (c). A sluice gate opening is provided at the Right main CHR of Bisalpur Dam (Fig. 4 d).

5. HYDRO POWER POTENTIAL ASSESSMENT

(i) Inflow Assessment in last 10 Years

Rajasthan is a state with large spatial and inter annual variation in the rainfall and hence there is large variation in water inflow in reservoirs. Water level and volume data for last 10 years (from 2008 – 2018) are collected from Rajasthan Monsoon Report 2013 and 2018 [7]. In the present study, focus is on the reservoirs which have significant capacity & head and have average water inflow of more than 70% in last 10 Years (Table 3). Due to the high rainfall and hilly terrain, such reservoirs are mostly located in Southern part of the state. Many of the reservoirs in other parts of the state receive very low inflow in comparison to their full capacity (Table 4). Change in rainfall pattern, encroachment of small streams and construction of check dams & farm ponds may be responsible for this change [8].

(ii) Water Level-volume Curve Assessment

These reservoirs generally follow the non-linear relationship between water level and volume. As mentioned in the previous section, the water level and volume relation is used to find the water level corresponding to the 25 and 50% capacity of the reservoir. Few reservoirs received 80 % or more water of full capacity in last 10 years. For them the water level corresponding to 25 and 50 % capacity is taken from the reservoirs with similar full reservoir level. The corresponding energy output is calculated for that volume and head.

(iii) Energy Output Assessment

The major purpose of these reservoirs is to supply water for irrigation. As per the reservoir capacity and crop pattern of the Rajasthan generally these reservoirs are running for two - three months during winter period. The rated energy output of the turbine is calculated by equation 1. In the present study global efficiency ratio is taken as unit for calculating potential energy.

$$P = Q * \rho * g * H * \eta \quad \dots(1)$$

Here P = Mechanical Power in kW

Q = Flow rate in the pipe (m^3/s)

ρ = density (kg/m^3)

g = Gravitational acceleration (m/s^2)

H = Head (m)

η = Global efficiency ratio

The efficiency of turbines depends on the velocity of jet and specific speed of the turbine. As mentioned earlier the varying head of the reservoir is the major challenge in

Table 3 : Hydro Power Potential of Irrigation Reservoirs

Sr. No.	Name of the Reservoir	District	Capacity at FTL (MCM)	Full Tank Level (FTL) (m)	Average Water inflow (2009-2018) (% of full capacity)	Top 75% Volume (MCM)	Top 50% Volume (MCM)	Water level for 25% of the total volume (m)	Water level for 50 % of the total volume (m)
1	Bisalpur Dam*	Tonk	250.0	6.0	67.0	200.0*	200.0*	5	5.00
2	SomKamlaAmba	Dungarpur	172.5	13.0	97.4	129.4	86.3	6	9.00
3	Jakham Dam	Pratapgarh	142.0	31.0	89.5	106.5	71.0	16.5	23.00
4	Parwati	Dholpur	120.9	28.1	71.3	90.7	60.4	17	24.00
5	Gudha	Bundi	95.6	10.5	73.7	71.7	47.8	4.5	7.25
6	Chappi Dam	Jhalawar	82.6	12.9	92.9	61.9	41.3	4	8.20
7	Bhimsagar	Jhalawar	76.6	12.2	79.2	57.4	38.3	6.5	9.00
8	Gambhiri	Chittorgarh	55.0	7.0	85.6	41.3	27.5	3.2	5.00
9	Kalisindh**	Jhalawar	54.4	10.0	88.3				
10	Chauli Dam	Jhalawar	53.5	9.4	67.6	40.1	26.8	4.2	6.80
11	Baretha	Bharatpur	52.7	8.8	76.2	39.5	26.3	3.7	6.25
12	Gaagrin	Jhalawar	52.6	7.0	100.0	39.5	26.3	3.5	5.00
13	Alnia	Kota	43.7	10.1	71.3	32.8	21.9	6.4	7.80
14	Bethli	Baran	37.2	9.6	76.2	27.9	18.6	3.1	6.00
15	SomKagdar	Udiapur	36.2	14.0	100.0	27.2	18.1	6	9.50
16	Orai	Chittorgarh	35.3	9.5	92.0	26.5	17.6	3.4	6.20
17	Gopalpura	Baran	32.7	8.2	73.6	24.5	16.3	3.1	5.50
18	Ghosunda	Chittorgarh	31.8	8.0	89.4	23.9	15.9	3	5.40
19	Udaisagar	Udiapur	31.2	7.3	84.1	23.4	15.6	2.6	5.10
20	Ram Sagar	Dholpur	30.8	7.7	72.9	23.1	15.4	2.7	5.20
21	Lihasi	Baran	30.8	6.0	87.9	23.1	15.4	2.3	4.80
22	Sawanbhado	Kota	29.8	13.6	77.9	22.4	14.9	6	9.50
23	Vardha	Bundi	29.0	6.4	94.3	21.7	14.5	2.9	4.80
24	Bilas	Baran	28.9	8.1	82.8	21.7	14.5	3.4	5.50
25	Bassi	Chittorgarh	23.2	11.0	92.4	17.4	11.6	3.2	6.50

Table 3 : Hydro Power Potential of Irrigation Reservoirs (contd.)

Sr. No.	Name of the Reservoir	District	Potential Hydro power for 75% of total Volume (kWh/Year)	Potential Hydro power for 75% of total Volume	Potential Hydro power for 50% of total Volume	Potential Hydro power for 50% of total Volume
			(with minimum level)	(with average level)	(with minimum level)	(with average level)
1	Bisalpur Dam	Tonk	2725000	2997500	2725000	2997500
2	SomKamlaAmba	Dungarpur	2115281	3349195	2115281	2585344
3	Jakhm Dam	Pratapgarh	4789518	6894003	4450865	5224929
4	Parwati	Dholpur	4199825	5572179	3952776	4291232
5	Gudha	Bundi	879037	1467016	944151	1157074
6	Chappi Dam	Jhalawar	675010	1425958	922513	1186892
7	Bhimsagar	Jhalawar	1016919	1462799	938694	1105573
8	Gambhiri	Chittorgarh	359765	573938	374756	450082
9	Kalisindh	Jhalawar				
10	Chauli Dam	Jhalawar	459231	741876	495678	589346
11	Baretha	Bharatpur	398186	674763	448407	541317
12	Gaagrin	Jhalawar	376254	564382	358338	430005
13	Alnia	Kota	571858	735373	464634	531947
14	Bethli	Baran	235939	483294	304437	395768
15	SomKagdar	Udiapur	443903	739838	468564	579539
16	Orai	Chittorgarh	245221	463396	298112	376247
17	Gopalpura	Baran	206858	375347	244671	303614
18	Ghosunda	Chittorgarh	195035	357564	234042	290386
19	Udaisagar	Udiapur	165630	315652	216593	263521
20	Ram Sagar	Dholpur	170179	326176	218501	269975
21	Lihasi	Baran	144779	261232	201432	226611
22	Sawanbhado	Kota	365668	597257	385983	469274
23	Vardha	Bundi	171761	275706	189529	221315
24	Bilas	Baran	200819	339620	216569	267759
25	Bassi	Chittorgarh	151859	336937	205642	276826
		Total	2,12,63,533	3,13,31,001	2,13,75,169	2,50,32,074

* Major purpose of the Bisalpur Dam is to supply drinking water to the cities and villages of Ajmer, Jaipur and Tonk district. Hence, 200 - 250 MCM water is allocated for the irrigation purpose if the reservoir is full. The full tank level of Bisalpur Dam is 315.5 m and bed level of the right main canal is 309.0 m.

** Major purpose of Kalisindh Dam is to supply water to Kalisindh Thermal power plant. Hence, this reservoir is not included in the energy calculation.

design a suitable turbine for these reservoirs. For simplicity, the potential energy is calculated for top 75% and 50% volume with taking water level corresponding to 25% and 50% of the total volume. Similarly, the potential energy is also calculated for average of water level for top 75% and 50% of the volume.

6. RESULTS AND DISCUSSION

The potential energy output from the reservoirs is calculated in Table 3. Total volume of the reservoirs considered in the

present study is 1629 MCM. The potential energy output is 21.26, and 21.37 million kWh for top 75 and 50% of the total volume and water level corresponding to the 25 and 50% of the volume. When average water level is taken, these values are 31.33 and 25.03 million kWh, respectively.

Advantages

- Without creating new storage facilities, power can be generated from existing reservoirs with small modifications in the canal head regulators.

- (ii) It gives a method to generate electricity from renewable energy source during winter period when availability from solar panels is decreased due to fog and shorter span of sun light.
- (iii) Generate employment for local skilled labour.
- (iv) Add one more benefit to the water resources projects.
- (v) The concept is also useful for other states. Peninsular Indian states have more potential in comparison to Rajasthan due to high rainfall and more hilly terrain.

Limitations

- (i) This output is very low in comparison to other possible methods of energy generations. Also, there is a variation in inflow of the reservoirs.
- (ii) The efficiency of hydraulic turbines depends on the various factors especially discharge and head. Varying head is the major challenge in its design with optimum efficiency.
- (iii) Another major limitation is the opening of gates and connections with the head race of turbines. As the head varies, it is also required to adjust the opening of sluice gates.
- (iv) A separate design will be required for most of the cases which is suitable for that flow rate, head and canal head regulator.
- (v) Water availability is only for short duration and hence the turbines will remain ideal for rest of the period.

Suggestions to overcome the limitations

- (i) Design the turbines, which are suitable both for irrigation reservoirs and low head check dams on rivers, will make these methods more feasible and economical. For example, as shown in Fig. 5, a check dam was constructed on Mej River near Lakheri town in Bundi district. This river have sufficient flow during monsoon and winter period. Approximate head is around 5 m.
- (ii) Many reservoirs in southern part of the state overflows during monsoons and the same water can be utilized for power generation, which will increase the overall output from the turbines. The reservoirs located in southern part of the state, which is not included in the present study due to the volume constraint can also be used for the power generation.
- (iii) In future, a mega inter basin water transfer project is also proposed in Rajasthan from the Chambal to Banas basin. As presented in Table 4, the reservoirs in central and eastern Rajasthan also get some inflow during monsoon. Whatever, water will be transferred to these reservoirs, it will be added into the live storage and can be utilized for power generation.
- (iv) An entrepreneur effort to harness the hydro power from these reservoirs will be required.



Fig. 5 : Check Dam on Mej River near Lakheri Town in Bundi District (Approximate head is 5 m)

7. CONCLUSION

Hydro power potential of low head irrigation reservoirs of Rajasthan (India) was assessed in the present study. 25 reservoirs with total capacity of 1629 MCM were selected on the basis of their volume, head and probability of getting inflow. The total hydro power potential is 21.26 and 21.37 million kWh for top 75 and 50% of the total volume and water level corresponding to the 25 and 50% of the volume. It increases up to 31.33 and 25.03 million kWh when average water level is taken for top 75 and 50% of the total volume. It can also be observed that many reservoirs have significant volume and head, yet they receive very less average inflow in comparison to their designed capacity. A slight modification in canal head regulators is necessary to connect these regulators with the head race of turbines. Varying head, variability in inflow and short operation time are the major challenges in turbine design and energy production. However, by designing a portable turbine which can be used at both canal head regulators and check dams will make the option feasible and economical. Similar type of study can be proposed for other states of the country.

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Table 4 : Reservoirs receiving average inflow less than 70% from 2009-2018

Sr. No.	Name of the Reservoir	District	Capacity at FTL (MCM)	Full Tank Level (FTL) (m)	Average Water inflow (2009-2018) (% of full capacity)
1	Jaisamand	Udiapur	415.1	8.4	65.3
2	Jawai Dam	Pali	207.5	18.9	57.1
3	Sikri	Bharatpur	127.4	3.6	0.0
4	Rajsamand	Rajsamand	107.3	9.2	34.5
5	Meja	Bhilwara	84.1	9.2	15.8
6	Sardarsamand	Pali	82.2	7.6	6.6
7	Morel	Dausa	76.6	9.3	29.8
8	Ramgarh	Jaipur	75.0	19.8	0.1
9	Hemawas	Pali	62.6	8.5	46.8
10	Panchana	Karoli	59.5	258.6	56.5
11	Sareri	Bhilwara	55.8	7.0	10.9
12	Galwa	Tonk	48.8	6.1	63.3
13	Mashi	Tonk	48.1	3.1	40.6
14	Arwar Dam	Bhilwara	48.0	7.3	19.9
15	Tordisagar	Tonk	47.1	9.2	22.9
16	Sai Dam	Udiapur	45.8	10.9	61.0
17	Kalisil	Karoli	41.8	7.6	64.6
18	Wagan	Chittorgarh	40.7	5.0	43.2
19	West Banas	Sirohi	39.1	7.3	63.2
20	Chaparwara	Jaipur	35.0	5.2	20.7
21	Juggar	Karoli	35.0	8.2	46.4
22	MatraKundia	Chittorgarh	33.6	6.9	41.5
23	Badgaon	Chittorgarh	31.5	7.6	31.4
24	SukliSelwada	Sirohi	29.5	5.5	31.5
25	Dheel	SawaiMadhopur	27.7	4.9	57.7
26	Jaisamand	Alwar	27.0	7.0	6.6
27	Surwal	SawaiMadhopur	26.0	4.6	66.0
28	Chitoli	Jaipur	24.4	6.9	0.0
29	Ora Tank	Sirohi	22.6	7.5	38.7
30	Madhosagar	Dausa	22.6	10.7	0.5

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