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# Experimental investigations of 3.75 kW laboratory scale pico Kaplan hydraulic turbine

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**ABSTRACT**

Experimental investigations of 3.75 kW Pico Kaplan turbines have been carried out in this communication. The turbine is utilized for the experimental purpose for the students and it is procured under TEQIP-III project of World Bank. The load test of the turbine has been done which run at 50% capacity and presented the main and operating characteristic curves. It is observed that the efficiency of the turbine will improve at low speed, high brake power and high discharge. The discharge is also depending on the available head and the quantity of water. So, the turbine efficiency is also improved with respect to increasing the discharge. At the increasing the specific speed the discharge will also be increased linearly. The Pico Kaplan turbine can be used for runways water likes in Canals, rivers and no dam is required. The basic design is very simple and it is very common because it has vast applications for small, pico and micro power generation. It can be used in lot of regions like Himachal, Uttarakhand, Jammu & Kashmir, Eastern State (Assam, Arunachal Pradesh, Meghalaya, and Manipur), Punjab, Karnataka, Kerala, West Bengal, Maharashtra and Rajasthan states of India. This study will be useful for the researcher in the area of small hydro power plants.



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## 1. INTRODUCTION

The Kaplan turbine was developed and patented by Austrian Professor Viktor Kaplan in 1913, where both the blade and wicket gates are adjustable for allowing the wide range of applications. It means the adjustable blade and wicket can helps to achieve efficiency over a wide range of water level and flow. The criteria of selection of Kaplan turbine based on the techno-economic consideration for the available water head 10 to 60 m, and the minimum load up to which Kaplan turbine may be continuously operated without undue cavitations and vibration is 30-40%. In this regards the permissible pressure rise and speed rise for Kaplan turbine is specified by 30-50% and 30-65% respectively [1].

As per the U.S. design practice the power specific speed is given by $\mathrm{N} = \frac{\mathrm{nP}^{1/2}}{\mathrm{H}^{5/4}}$ , Where P is the power output in kW, n is the revolutions per minute, H is the water head available in meter and the N is the specific speed which applies at the point of maximum efficiency. The type of turbine selection as per specific speed is given in Table 1. It is found that the specific speed of the Pelton lies between 3-20, Francis 10-90, Deriaz up to 100 and Propeller or Kaplan turbine between 20 to 260 [2].

Khaing *et al*. [3] studied the design and simulation with CFD of 10 kW Kaplan turbine. It expressed the runner design and calculated the runner and hub diameters by 395 mm and 122 mm respectively. Slameto and Puguh [4] investigated the utilization of Kaplan turbines for micro hydro power plant (PLTMH) 5 kW power plants and observed the highest efficiency at guide vane 40 opening means 57.14% with head of 4.15 m and a discharge of 0.074 $m^3$/sec at certain impeller position. Mon studied the design and performance testing of 5 kW axial flow hydro turbine at 2.5 m head in Myanmar [5].

Table 1. Turbine selection on the basis of specific speed [2]

| S. No. | Types of turbine | Specific speed |
|---|---|---|
| 1 | Pelton | 1-20 |
| 2 | Francis | 10-90 |
| 3 | Deriaz | up to 110 |
| 4 | Propeller or Kaplan | 70-260 |

Peczkis *et al.* [6] experimentally and numerically studied the influence on blade number in a small water turbine and found that the the designed turbine efficiency reached up to 84% for 5 blades irrespective of 72% at 4 blades. Abeykoon and Hantsch [7] analyzed the Kaplan turbine runner wheel through ANSYS software and observed that that the adjustment of design parameter can improve the efficiency where in ANSYS model the changes like number of blade on wheel, and the size of blade and outlet angles can change easily. It is observed that 93.01% efficiency can be achieved by optimize these three parameters.

Amiri [8] studied the experimental investigations of flow in a Kaplan runner for steady state and transient conditions. Amiri et al. also investigated the best efficiency points of a Kaplan turbine runner [6]. Ko and Kurosawa [9] numerically simulated the turbulence flow in a Kaplan turbine and evaluated the turbine performance prediction accuracy. Khan *et al.* [10] carried out the modelling, simulation and fabrication of 5.8 kW micro Kaplan turbine which have 0.35 $m^3$/s discharge rate and 2 m head and the runner diameter 34 cm with 4 blades and 10 guide vanes. It was also observed the successful generated acceptable power levels from the low head condition of 0.92 m. Abubakar *et al*.[11] studied the modelling and Analysis of a very low head (1.16 m), 60 kW Kaplan turbine runner blades for rural area of Punja (India). It was observed the runner diameter by 1.25 m, hub diameter 0.3 m. do Nascimento *et al.* [12] investigated the performance of an Indalma hydro turbine (small hydroelectric plants (CERPCH/UNIFEI-MG-Brazil).). It was observed the 80.8% efficiency at flow rate of 0.012 $m^3$/s

Prodanovic *et al.* [13] studied the determination of operating parameters of turbine for micro hydroelectric power plant for optimal use of hydropower. It was stated that the higher head means a low discharge is required for same output power and efficiency. The studies [9], [14]–[18] on design and performance investigation of a hydraulic mini turbine, installation and testing of a small hydropower turbine, numerical simulation of turbulence flow, draft tube effect and performance analysis of grid integrated doubly fed induction generator for a small hydropower were carried out by the various researchers. This communication is deals with the performance analysis through load testing method of a 3.75 kW in situ Kaplan turbine test rig, where Eddy current dynamometer is used. This study is very useful for the researchers of the same field.

## 2. METERIAL AND METHOD

### 2.1. Hydro power plants scenario in India

As per the global scenario, India is the 5th in terms of exploitable hydro-power potential. It means India has immense hydro-power potential which is approximately 1,48,700 MW as per CEA assessment [18]. The basin wise potential assessed by CEA is given in Table 2. Installed hydro power generation capacity as on 31 March 2022 is 46723 MW which is equivalent to the 11.7% of total power generation in India or 31% of total basin-wise hydro power installed capacity [19]. The annual electricity generation from hydropower plant in India is presented in Figure 1. It means it has a big role in power production [20].

Table 2. The basin wise hydropower assessed potential in India [18]

| Basin/rivers | Probable installed capacity (MW) |
|---|---|
| Indus basin | 33,832 |
| Ganga basin | 20,711 |
| Central Indian river system | 4,152 |
| Western flowing rivers of southern India | 9,430 |
| Eastern flowing rivers of southern India | 14,511 |
| Brahmaputra basin | 66,065 |
| Total (A) at 60% load factor | 1,48,701 |
| Pump storage project (56 nos.) (b) | 94,000 |
| Small, mini and micro HPP (C) | 6,782 |
| Total (A+B+C) | 2,49,483 |

The Pelton, Francis and Kaplan turbine are using for hydro power generation based on the available head of water. The Kaplan/propeller type turbine-based power projects are listed in Table 3 (in Appendix), and canal falls with vertical semi-Kaplan turbines with Syphon intakes are listed in Table 4 (in Appendix). It is observed that approximately twenty-seven hydropower plants (1441.55 MW throughout India) are already working on Kaplan turbine (vertical, horizontal and bulb type Kaplan turbines), six (5.25 MW) semi-Kaplan hydropower plants with siphon intake are under commissioning (mostly in Bihar), and one (0.7 MW) is already commissioned in the year of 2010. The probable installation capacity of hydropower plant is very high and there is lot of scope for the work for various locations and types as micro, mini, medium and large capacity. The micro/small Kaplan turbine can be installed in canals where small head like 2-5 meters is available. Chambal river is situated in Kota (Rajasthan), where canal irrigation system is most popular and these canals (right and left main canals) are very large capacity and working continuously for eight months (September to April) in a year. The Rajasthan government can think over the installation of Kaplan turbines at various places in these canals.

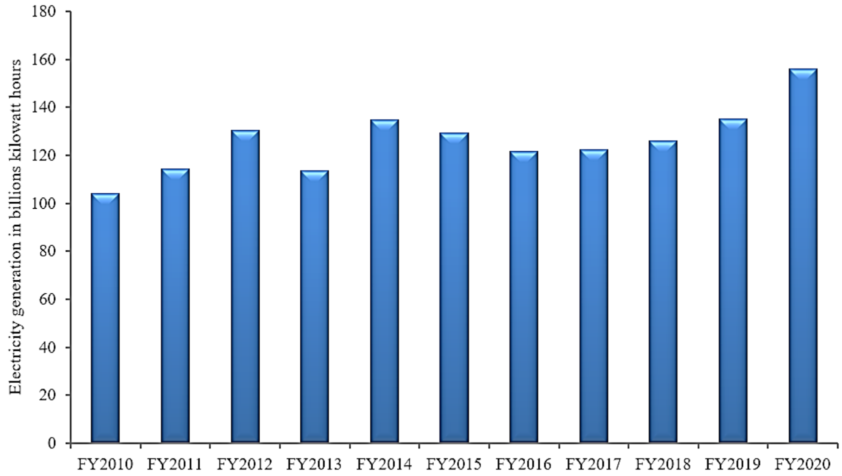



Figure 1. Annual electricity generation from hydropower plants in India [20]

### 2.2. Experimental setup

A 3.75 kW micro hydro turbine test rig is situated in the ME lab (25.143072°N, 75.803933°E) in Mechanical Engineering Department, Rajasthan Technical University Kota (India). The photo of the test setup is given in Figure 2 which is procured under TEQIP-III project. The 20 m water head is generated through the 20 hp kirloskar monoblock pump (size: 80×80 mm). The Kaplan turbine is having the 4-runner blade and 8 guide vanes. The runner hub diameter and outside diameters are 78 mm and 200 mm respectively. Water cooled Eddy current dynamometer (capacity 3.75 kW or 10.19 Nm, make-technomech) is fitted with the turbine test rig. The strain gauge of make-sensomatic (capacity 100 kgf or 10.19 Nm, model: SB) is used for measuring the brake force applied on the turbine shaft. A 3.75 kW hydraulic pump is used to supply the water to the Kaplan turbine. The other specifications of the test rig are given in the Table 5 and 6.


Figure 2. 3.75 kW Kaplan test rig

Table 5. Specification of the test set-up

| S.No. | Name | Specification |
|---|---|---|
| 1. | Centrifugal pump | 80×80 mm coupled with motor/make-kirloskar |
| 2. | Net Head | 20 m approx. |
| 3. | Normal speed | 1500 rpm approx |
| 4. | Motor and centrifugal pump | 20 HP monoblock pump (make-kirloskar) |
| 5. | Pump Size | 80×80mm |
| 6. | Turbine normal speed | 1200rpm |
| 7. | Runner outside diameter | 200 mm |
| 8. | Hub diameter | 78 mm |
| 9. | Number of runner blades | 4 |
| 10. | Number of guide vanes | 8 |
| 11. | Flow measurement orifice meter | 80 mm |
| 12. | orifice meter of throat | 53 mm |
| 13. | Pressure gauge range | 4 kg/cm$^2$ |
| 14. | MS pipe for supply of water to the turbine | 80 mm diameter |

Table 6. Standard data taken for the calculations

| S. No. | Symbol | Description | Data |
|---|---|---|---|
| 1. | g | Acceleration due to gravity | 9.81 m/sec$^2$ |
| 2. | d1 | Inlet area of orifice-meter at diameter | 0.080 m |
| 3. | d2 | Throat area orifice-meter at diameter | 0.053 m |
| 4. | a1 | Inlet area of orifice-meter at area | 0.020096 m$^2$ |
| 5. | a2 | Throat area of orifice-meter at area | 0.00882 m$^2$ |
| 6. | Cd | Coefficient of discharge | 0.65 |
| 7. | P1-P2 | Difference of pressure across the limbs of orifice-meter | |

### 2.3. Mathematical modelling

The selection of turbine is depending on the basis of water quantity and head availability at the site. In situ, the head is decided by the configuration of water supply pump and the pressure difference at the delivery side of the pump where orifice is to be used for measurement. The water is evaluated by the (1).

$$Total\ Head\ H = Pressure\ difference\ (P_1 - P_2) \times 10\ in\ meter \tag{1}$$

Where P1 is the pressures in the pump discharge/turbine inlet pipe and $P_2$ is the pressure at the orifice throat. The theoretical discharge can be calculated by the (2).

$$Q = C_d.\frac{A_1 A_2 \cdot \sqrt{(2g(P_1 - P_2)}}{\sqrt{{A_1}^2 - {A_2}^2}}\ \mathrm{m^3/sec} \tag{2}$$

Where $C_d$ is the coefficient of discharge (0.65), $A_1$ and $A_2$ are the cross-sectional areas of the supply pipe and the throat of the orifice. The Indicated power or water input power can by (3).

$$IP = \frac{\rho g Q H}{1000}\ kW \tag{3}$$

Where ρg is the specific weight of water = 9.81 kN/m$^2$.

The power output or break power can be calculated by the (4):

$$BP = \frac{2\pi N T}{60000} kW \tag{4}$$

where N is the RPM and T is the torque. The efficiency of the Kaplan turbine can be evaluated by the (5):

$$\eta = \frac{BP\ (Output\ )}{IP\ (Input)} \times 100\% \tag{5}$$

where, BP and IP are the brake power and indicated/input power. The specific speed of the Kaplan turbine can be calculated by the (6):

$$N_s = \frac{N\sqrt{P}}{H^{5/4}} \tag{6}$$

## 3. RESULTS AND DISCUSSION

Mainly two types of performance characteristics curve have been presented these are described as follows:

### 3.1. Main or constant head characteristics

The basis of the main characteristic curves is to plot the varying velocity curve. The velocity or speed is taken on X axis and discharge, power, and efficiency taken over Y axis. The velocity/speed can be varied with the variable gate openings or by change of load on dynamometer. The main characteristic curves are shown in Figures 3(a)-(e).

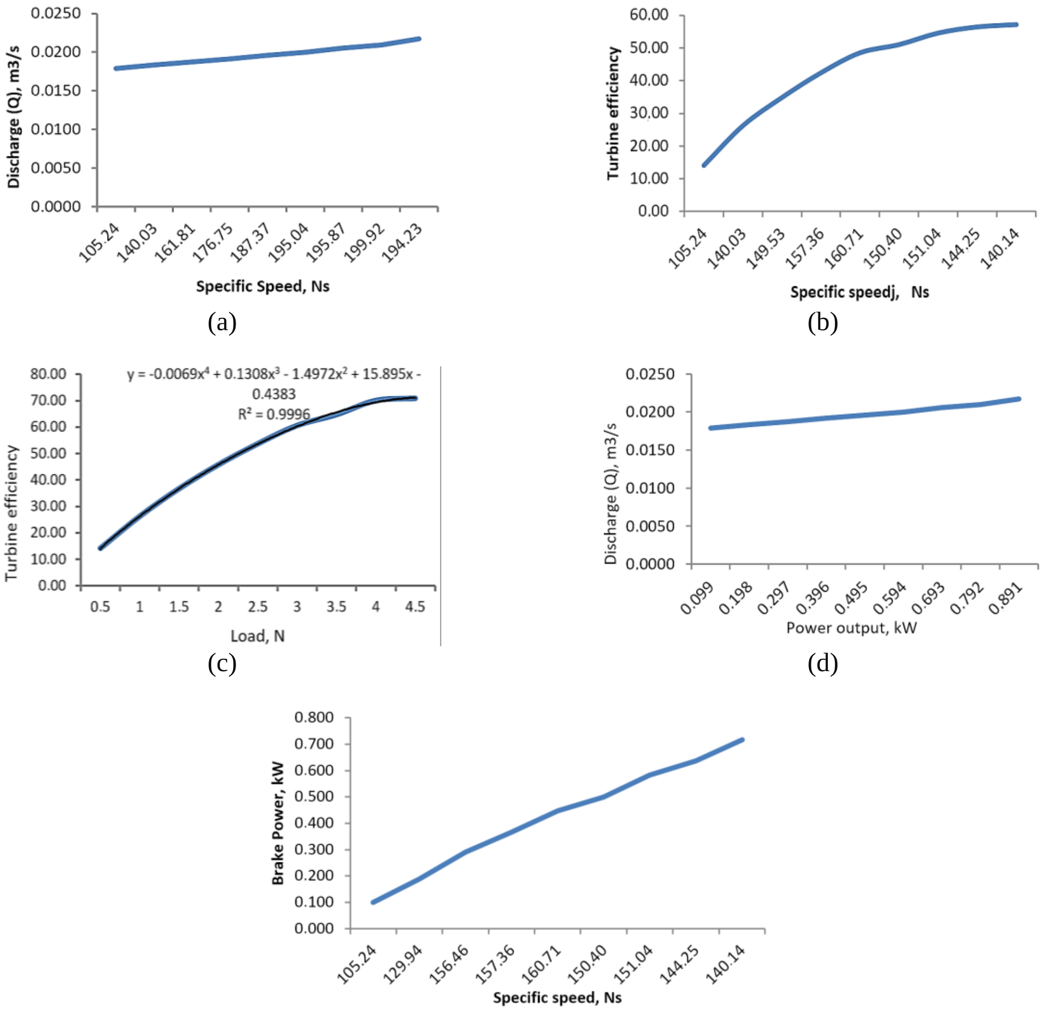
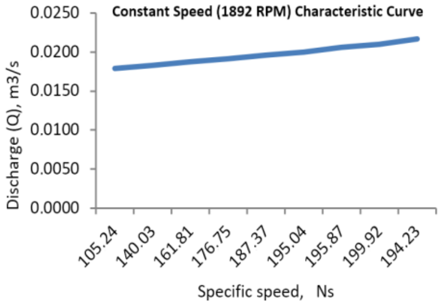



Figure 3. Characteristic curve for Kaplan turbine at 100% gate opening of (a) discharge v/s specific speed, (b) turbine efficiency v/s specific speed, (c) turbine efficiency v/s load, (d) discharge v/s power output, and (e) brake power v/s specific speed

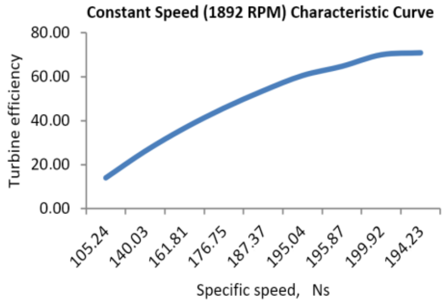
It is found that the turbine is performed at 50% capacity. The discharge is increasing with the increasing the specific speed as well as increasing the power output. The turbine efficiency is also increasing with increasing the specific speed as well as the increasing the load on the strain gauge (dynamometer). The initially all the characteristics curves are fully matched with the theoretical results presented in the books/papers [21], [22]. The theoretical discharge from the pump is 0.076150 $m^3/s$.

### 3.2. Operating or constant speed characteristics

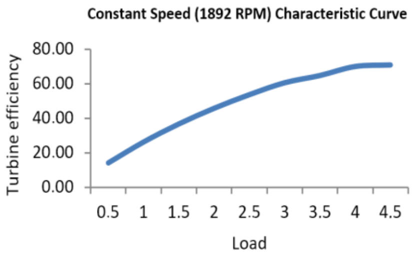
The operating characteristics or constant speed characteristics of the Laboratory scale Kaplan are shown in Figures 4(a)-(d), where constant speed is taken by 1892 RPM. The discharge and mechanical efficiency versus specific speed, brake load versus mechanical efficiency and brake power versus mechanical efficiency are presented and found that discharge and mechanical efficiencies are increasing with increasing in Ns, load and brake power. The maximum efficiency is observed slightly than the variable speed characteristics.



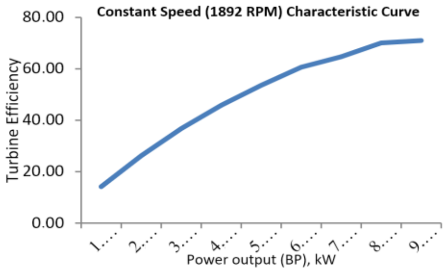
(a)



(b)



(c)



(d)

Figure 4. Operating characteristics/constant speed characteristics at 100% gate opening of (a) discharge v/s specific speed, (b) turbine efficiency v/s specific speed, (c) turbine efficiency v/s load and (d) turbine efficiency v/s power output

### 3.3. Full load performance curve

The Kaplan turbine is also operating on full load for performance testing and the efficiencies are calculated at various positions like: full gate opening (A position), 3/4 gate opening (B Position), half gate opening (C Position) and quarter gate opening (D position), it is called main characteristics and shown in Figure 5. It is found that the discharge rate is increasing with increasing the specific speed and also observed higher discharge for higher gate opening.

The performance of the Kaplan turbine on various Load/torque is shown in Figure 6. It is observed that the maximum efficiency of various positions is shifted to the left side when gate opening is transformed toward quarter side. The maximum efficiencies evaluated by 98.49, 85.08, 79.13, and 76.62 at A, B, C, and D positions respectively.

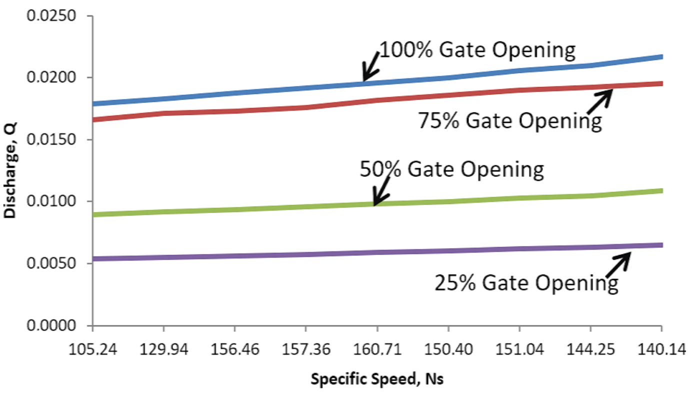



Figure 5. Characteristic curves at various gate opening

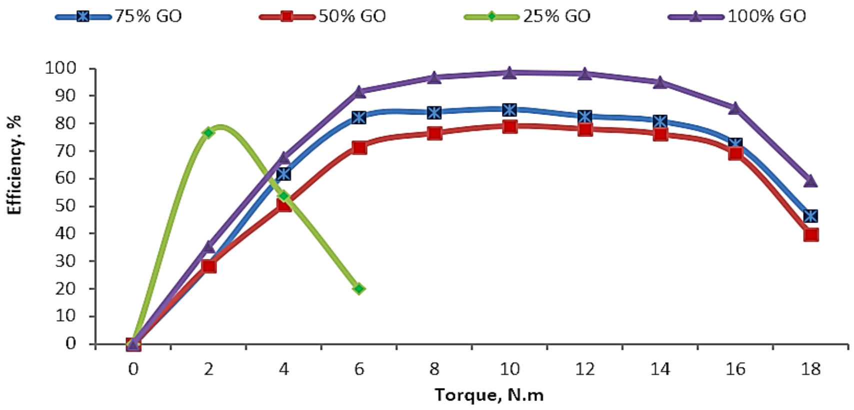



Figure 6. Efficiency v/s torque curve

## 4. CONCLUSION

The experimental evaluation of 3.75 kW Kaplan turbine have been studied and presented the main and operating characteristic curves. Both the characteristics curves have been presented in the books based on the gate openings it means at the basis of the change of water supply to the turbine and by which we can change the turbine speed. In this study brake load is used to change the speed means it is a performance testing of laboratory scale turbine where it operates at approximately 50% capacity. The characteristic curves are well matched with the available studies.

The Kaplan turbine of 3.75 kW is a Pico turbine and it can be used for runways water likes in Canals, rivers and no dam is required. The basic design is very simple and it is very common because it has vast applications for small, pico and micro power generation. It can be used in lot of regions like Himachal, Uttrakhand, Jammu and Kashmir, Eastern State (Assam, Arunachal Pradesh, Meghalaya, and Manipur), Punjab, Karnataka, Kerala, West Bengal, Maharashtra and Rajasthan states of India.

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## APPENDIX

Table 3. Typical Indian project data of Kaplan/propeller turbine [23]

| S.No | Power Station | Agency | No. of units x size (MW) | Head (M) | Speed (RPM) | Year of Commissioning (expected) | Specific speed ($N_s$) | Type of turbine | Specific speed H [22] |
|---|---|---|---|---|---|---|---|---|---|
| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. |
| 1. | Ukai | GEB | 4 x 75 | 47.8 | 150 | 1974 | 395.82 | Vertical Kaplan | 58 |
| 2. | Sardar Sarovar (CHPH) | SSNNL | 5 x 50 | 36 | 136.4 | 2004 | 418.88 | | 59 |
| 3. | Garhwal Risikesh Chilla | UPSEB | 4 x 36 | 32.5 | 187.5 | 1980 | 555.22 | | 60 |
| 4. | Obra | UPSEB | 3 x 33 | 20.4 | 115.4 | 1970 | 285.59 | | 61 |
| 5. | Baliamela | APSEB | 2 x 30 | 35.8 | 187.5 | 2008 | 449.13 | | 62 |
| 6. | Balimela Dam | APSEB | 2×30 | 35.8 | 187.5 | 2008 | 449.13 | | 28. |
| 7. | Donkarai | APSEB | 1×25 | 21.0 | 136.4 | 1983 | 580.99 | | 29. |
| 8. | Mukerian Phase-III & IV | PSEB | 6×19.5 | 22.0 | 166.7 | 1989 | 591.68 | | 30. |
| 9. | SYL Phase-I | PSEB | 2×18 | 15.3 | 136.4 | 2010 | 732.41 | | 31. |
| 10. | UBDC Stage-II | PSEB | 3×15 | 17.1 | 166.7 | 1989 | 711.05 | | 32. |
| 11. | UBDC | PSEB | 3×15 | 17.1 | 150.0 | 1971 | 639.82 | | 33. |
| 12. | Mukerian Phase-I & II | PSEB | 6×15 | 16.8 | 150.0 | 1983 | 654.13 | | 34. |

Table 3. Typical Indian project data of Kaplan/propeller turbine [23] (continue)

| S.No | Power Station | Agency | No. of units x size (MW) | Head (M) | Speed (RPM) | Year of Commissioning (expected) | Specific speed ($N_s$) | Type of turbine | Specific speed H [22] |
|---|---|---|---|---|---|---|---|---|---|
| 13. | Bansagar Phase-II | MPEB | 2×15 | 21.0 | 166.7 | 2002 | 550.01 | | 35. |
| 14. | Kabini | SP&ML | 2×10 | 18.0 | 200.0 | 2003 | 653.29 | | 36. |
| 15. | Pochampad | APSEB | 3×9 | 21.4 | 250.0 | 1987 | 624.04 | | 37. |
| 16. | Mukerian Stage-II | PSEB | 2×9 | 8.23 | 125.0 | 2009 | 1030.26 | Bulb turbine | 38. |
| 17. | Singur | APSEB | 2×7.5 | 18.29 | 250.0 | 1999 | 693.22 | Vertical Kaplan | 39. |
| 18. | Teesta Canal | WBSEB | 4×7.5 | 8.0 | 142.9 | 1999 | 1113.95 | | 40. |
| 19. | Bhadra R.B. | KPCL | 1×6 | 17.0 | 214.0 | 1998 | 581.56 | | 41. |
| 20. | Narayanpur | MPCL | 2×5.8 | 6.5 | 111.1 | 1999 | 987.31 | | 42. |
| 21. | Suratgarh | RSEB | 2×2 | 8.66 | 187.5 | 1992 | 683.57 | | 43. |
| 22. | Mangrol | RSEB | 3×2 | 7.27 | 166.7 | 1992 | 756.31 | | 44. |
| 23. | Sone Western Canal | BSHPC | 4×1.65 | 3.7 | 120.0 | 1993 | 1150.37 | | 45. |
| 24. | Dhupdal | FORBES Gokak Mills | 2×1.4 | 4.8 | 158.0 | 1997 | 1107.71 | | 46. |
| 25. | Nidampur | PSEB | 2×0.5 | 3.0 | 136.4 | 1985 | 935.54 | Horizontal propeller/ Kaplan | 47. |
| 26. | Dauhar | PSEB | 3×0.5 | 3.5 | 136.4 | 1987 | 771.58 | | 48. |
| 27. | Ganekal | KPCL | 1×0.35 | 3.69 | 136.4 | 1994 | 604.27 | | 49. |
| 28. | Kakatiya (19th Mile) | APSEB | 3×0.23 | 3.3 | 166.7 | 1987 | 688.37 | | 50. |
| 29. | Kakroi | Universit y of Roorkee | 1×0.1 | 1.9 | 125.0 | 1988 | 678.63 | | 51. |

Table 4. Projects on canal falls with vertical semi Kaplan turbines with syphon intakes (AHEC Project) [23]

| Sl. No | Power station | Sponsored/manufact user | No. of units x size | Speed (RPM) | Year/likely year of commissioning | Specific speed (Ns) | Type of turbine | Type of generator | Speed (RPM) |
|---|---|---|---|---|---|---|---|---|---|
| Bihar | | | | | | | | | |
| 1. | Shirkhinda SHP | HPP Energy(India) Pvt. Ltd. | 2×0.350 | 3.18 | 135 | 2010 | 744.89 | Vertical semi Kaplan with syphon intake | Synchronous Generator |
| 2. | BelsarSHP | HPP Energy (India) Pvt.Ltd. | 2×0.500 | 3.22 | 129 | Under commissioning /construction | 763.22 | Vertical semi Kaplan withsyphon Intake | Synchronous Generator Vertical |
| 3. | Tejpura SHP | HPP Energy (India) Pvt.Ltd. | 2×0.750 | 3.46 | 107 | Under commissioning /construction | 770.77 | Vertical semi Kaplan withsyphon Intake | Synchronous Generator Vertical |
| 4. | Rajapur SHP | HPP Energy(India) Pvt.Ltd. | 2×0.350 | 4.78 | 190 | Under commissioning /construction | 798.55 | Vertical semi Kaplan with iIntake gate | Synchronous generator vertical |
| 5. | Amethi SHP | HPP Energy (India) Pvt.Ltd. | 1×0.500 | 3.218 | 114 | Under commissioning /construction | 745.97 | Vertical semi Kaplan with sSyphon intake | Synchronous generator vertical |
| 6. | ArwalSHP | HPP Energy(India) Pvt. Ltd. | 1×0.500 | 2.926 | 103 | Under commissioning /construction | 757.83 | Vertical semi Kaplan with syphon intake | Synchronous generator vertical |
| 7. | Walidad SHP | HPP Energy(India) Pvt. Ltd. | 1×0.700 | 3.44 | 116 | Under commissioning /construction | 751.36 | Vertical Semi Kaplan with syphon intake | Synchronous generator vertical |

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