Planning of Canal Based Small Hydropower Scheme

Introduction

Energy is a basic requirement for economic development. Every sector of Indian economy - industry, agricultural, transport, commercial and domestic - needs input of energy. The installed electricity generating capacity in India at present is nearly 128 GW; of this thermal is 66%, hydro 26%, nuclear 3% and renewable 5% [1]. According to International Energy Agency, a threefold rise in India's generation capacity is expected by 2020. As the non-renewable fossil energy sources continues to deplete, and realizing the summits held at Brazil and Kyoto, to reduce the greenhouse gas emissions, hydro power has moved towards the top power development option to meet the increasing energy demand. Hydropower is the cheapest, non-polluting and uses renewable resource i.e. water. It is perhaps the oldest renewable energy technique known to mankind - for mechanical energy conversion as well as electricity generation. Hydropower represents use of water resources towards inflation free energy due to absence of fuel cost - with mature technology characterized by highest prime moving efficiency and spectacular operational flexibility.

The conventional large hydropower plants have problems like long gestation period, ecological changes, loss due to long transmission lines, submergence of valuable forest and underground mineral resources as well as there can be large gaps between investigations and realities. They also require rehabilitation of large population from area to be submerged. Due to all these factors large hydropower plants are unfavorable. On the other hand, small hydropower (SHP) projects are free from these problems. Such installations are environment friendly because they cause negligible or no submergence, minimal deforestation and minimal impact on flora, fauna and biodiversity. The worldwide contribution of SHP has grown substantially in the last ten years, in light of their less initial capital investment and low gestation period. In India, the potential of SHP is estimated as 15,000 MW. Of this, 4404 potential sites with an aggregate capacity of 10,477 MW have been identified. Already 581 small hydro schemes with total installed capacity of nearly 1,937 MW are installed and 207 schemes with another 561 MW are under various stages of implementation [2].

Canal based SHP development in Gujarat State

In most parts of the Gujarat, water is available in monsoon only. To support the agriculture sector, the state has a well-developed irrigation system. The energy available in the water can be utilized for electricity generation at the falls and thus the existing irrigation infrastructure (canals, dams) can serve the dual purpose of meeting the irrigation and energy requirements of the state. The electricity produced can be utilized in many ways: (i) it can be connected to the existing grid nearby or (ii) it can be utilized as a stand-alone power generating unit. The power may also be used as peaking power to meet the peak load by rescheduling the water releases.

Nadiad small hydropower project

A study has been carried out for sustainable development of SHP project on Nadiad branch canal. The view of the canal is shown in Fig.1. The Nadiad small hydropower project is proposed on the left bank of Nadiad branch canal, a branch canal of Mahi canal, which takes off from Mahi river at Wanakbori weir in Balasinor taluka of Kheda district in Gujarat. Nadiad branch canal is around 35.85 km long having design discharge of 85 cumecs. There exists a fall of 2.47 m at a chainage of 33,800 m. In order to utilize discharge and head available, a canal based small hydropower project is proposed on the left bank of Nadiad branch canal. The view of fall is shown in Fig 2.

Fig 1 Nadiad branch canal

Fig 2 Fall at chainage 33,800 m

Techno - economic studies

For planning of the SHP scheme, the project site was visited and basic data were collected from Mahi Irrigation Circle, Nadiad. It is found that the net head available for power generation is 2.3 m which comes in the category of ultra low head. The average discharge data for the period 1997 to 2007 i.e. 11 years were analyzed and flow duration curve is prepared as shown in Fig 3.

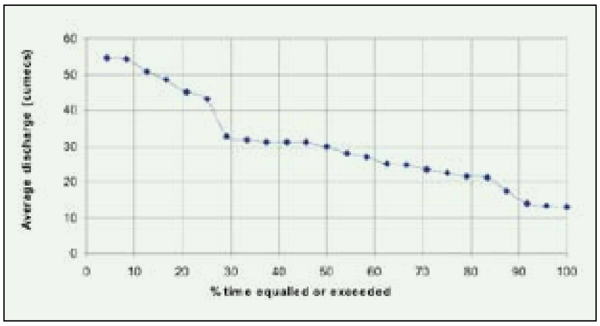

Fig 3 Flow duration Curve

Based on the head and discharge available, power potential and energy available were worked out considering turbine, gearbox and generator efficiency as 88%, 95% and 94% respectively, as shown in Table I. It can be seen that available power potential ranges from 233 to 969 kW. Thus, we can plan the installed capacity in this range. Accordingly, the alternative installations varying from 500 to 1000 kW have been considered and the annual energy generation, plant load factor were worked out for each alternatives and shown in Table I. Based on optimum energy generation, installed capacity of 800 kW has been found most suitable at a rated discharge of 45.12 cumecs. The annual average energy is worked out as 4.59 Million Units at 65.43% load factor.

Number and size of units

The discharge available is to be regulated through cross regulator, which is proposed on the existing fall. When excess water is available, rated discharge will pass through machines and rest will pass directly through Nadiad branch canal. Both discharge will meet at the confluence of tail race channel and Nadiad branch canal and then flow downwards. During lean period, all the water will be passed through machines. Further, single unit may be economically advantageous from an initial cost point of view, but considering large variation in discharge as shown in Fig.3, more than one unit is desirable. Accordingly 2 units of 400 kW each are selected for installation.

Selection of Turbine

For low head installations, the operating and installation costs are much higher compared to large

% time equalled or exceeded	Average discharge (cumecs)	Net Head (m)	Power potential (kW)	Power available at alternative installations (kW)					
				500	600	700	800	900	1000
4.17	54.67	2.3	969.42	500	600	700	800	900	969.42
8.33	54.36	2.3	963.83	500	600	700	800	900	963.83
12.50	50.77	2.3	900.26	500	600	700	800	900	900.26
16.67	48.66	2.3	862.77	500	600	700	800	862.77	862.77
20.83	45.05	2.3	798.72	500	600	700	798.72	798.72	798.72
25.00	43.23	2.3	766.53	500	600	700	766.53	766.53	766.53
29.17	32.79	2.3	581.32	500	581.32	581.32	581.32	581.32	581.32
33.33	31.84	2.3	564.64	500	564.64	564.64	564.64	564.64	564.64
37.50	31.19	2.3	552.97	500	552.97	552.97	552.97	552.97	552.97
41.67	31.07	2.3	550.92	500	550.92	550.92	550.92	550.92	550.92
45.83	31.03	2.3	550.13	500	550.13	550.13	550.13	550.13	550.13
50.00	29.92	2.3	530.44	500	530.44	530.44	530.44	530.44	530.44
54.17	28.02	2.3	496.79	496.79	496.79	496.79	496.79	496.79	496.79
58.33	27.09	2.3	480.33	480.33	480.33	480.33	480.33	480.33	480.33
62.50	25.23	2.3	447.44	447.44	447.44	447.44	447.44	447.44	447.44
66.67	24.91	2.3	441.69	441.69	441.69	441.69	441.69	441.69	441.69
70.83	23.38	2.3	414.60	414.60	414.60	414.60	414.60	414.60	414.60
75.00	22.43	2.3	397.64	397.64	397.64	397.64	397.64	397.64	397.64
79.17	21.59	2.3	382.75	382.75	382.75	382.75	382.75	382.75	382.75
83.33	21.36	2.3	378.75	378.75	378.75	378.75	378.75	378.75	378.75
87.50	17.60	2.3	312.12	312.12	312.12	312.12	312.12	312.12	312.12
91.67	13.98	2.3	247.81	247.81	247.81	247.81	247.81	247.81	247.81
95.83	13.22	2.3	234.49	234.49	234.49	234.49	234.49	234.49	234.49
100.00	13.15	2.3	233.19	233.19	233.19	233.19	233.19	233.19	233.19
			Average Power (kW)	**436.15**	**474.92**	**499.92**	**523.47**	**538.59**	**544.15**
			Annual Energy (MU)	**3.82**	**4.16**	**4.38**	**4.59**	**4.72**	**4.77**
			Plant Load Factor (%)	**87.23**	**79.15**	**71.42**	**65.43**	**59.84**	**54.41**

Table I - Power Potential and Energy Generation

installations. Hence, while selecting the turbine the greater considerations were given to the following aspects:

- The civil engineering work needs to be kept to a minimum.
- The equipment must be simple and robust with easy accessibility to essential parts for maintenance.
- Indian experience and Indigenous availability.

For a given range of head and discharge, the specific speed worked out as 746.45(metric). Accordingly, following types of axial flow turbines suitable for this range were considered.

- Vertical fixed blade Propeller turbine
- Vertical Semi Kaplan turbine with siphon intake
- Horizontal Kaplan (tubular) turbine

Fixed blade propeller turbine do not have any flow regulating mechanism which results in lower part load efficiency and hence they are better suited for the site which does not have much variation in discharge.

In case of Semi Kaplan turbine, the wicket gates are fixed but runner blades are adjustable, hence it is having better part load performance compared to Propeller turbine but not as good as Kaplan turbine which is having double regulating mechanism i.e. adjustable wicket gates as well as adjustable runner blades. This makes the Kaplan turbine costlier.

Vertical Semi Kaplan turbine with siphon intake, operates on the siphon principle i.e. the valve of intake flume chamber is closed and kept water tight and vacuum is created by a vacuum pump, which enables water to enter in the flume chamber and energize the runner.

When the machine reaches the synchronous speed, it is synchronized with the grid like any

Table II - Comparison of Turbines considered		
Horizontal Kaplan (tubular) turbine	**Vertical fixed blade Propeller turbine**	**Vertical Semi Kaplan turbine with siphon intake**
Risk of flooding of power house equipments	Risk of flooding of power house equipments	There is no such risk
It is difficult to stop the turbine rotation if gates have been stuck or seals have been damaged or silt has been accumulated on the sill beam. In such case, turbine continues to rotate at high speed which could be extremely damaging to the turbine rotating parts.	Same as Horizontal Kaplan turbine	Such problems are never faced as the machine can be brought to stand still condition by just breaking the siphon
The size of power house is large	The size of power house is small	The power house is compact in size, thus small
Intake and draft tube gates are essential	Intake and draft tube gates are essential	Intake and draft tube gates are not required, thus saving in cost
The cost of civil works is high	The cost of civil works is high	The cost of civil works is low
'S' type tubular turbine requires minimum straight length of intake channel, leading to higher cost	No such constraint	No such constraint, thus reducing civil costs and allowing for cost effective layout
Vacuum pump is not required	Vacuum pump is not required	Vacuum pump is required for siphon arrangement, which leads to additional cost

conventional turbine. Machines can be shut down just by breaking the vacuum. Since the turbine operates on a siphon principle, the intake and draft tube gates are not required, thus cost is reduced. The merits and demerits of these turbines are given in Table II.

Considering above, 2 units of Vertical Semi Kaplan turbine, 400 kW each, with Siphon intake having adjustable runner blades and fixed wicket gates is found most suitable [3-5].

Works

Civil Works

The major civil works consist of cross regulator, power channel, power house, tail race channel, approach road. The power house is proposed on the left bank of Nadiad branch canal, considering land availability. The general layout of project is shown in Fig 4.

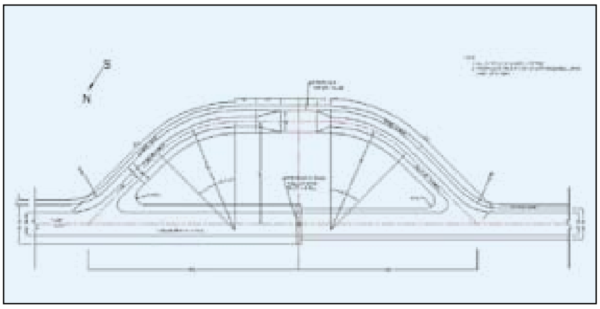

Fig 4 General layout of works

Cross regulator

Considering the low capacity of the project, the gated cross regulator is proposed on the existing fall to take the advantage of existing fall structure. Alternatively, cross regulator can be constructed on Nadiad branch canal between off taking point of power channel and existing fall. To pass the design discharge of Nadiad branch canal, i.e. 85 cumecs, through the gates of the cross regulator, the bed width at the fall requires to be increased from 21.34 m to 27.0 m. Other features of cross regulator are as follows:

No. and size of bays : 3 x 8 m

No. and size of piers : 2 x 1.5 m

Size of gates : 8 x 2.2 m

Power channel

The rated discharge for power generation is 45.12 cumecs. But, power channel is designed for 50 cumecs, considering 10% overloading of the turbine. The other features of power channel are as follows:

Cross-section : Trapezoidal (P.C.C. lined)

Length : 192.0 m

Bed width : 8.6 m

Water depth : 3.35 m (same as NBC)

Bed slope : 1:6000 (V:H) (same as NBC)

Side slope : 1.5:1 (H: V)

Free board : 0.91 m (same as NBC)

Power House

From seepage consideration, the distance between centre lines of power house and Nadiad branch canal is kept as 95 m. The power house building of size 20.0 mx10.5 mx26.0 m height is provided to accommodate two machines of 400 kW each, auxiliary equipments etc. The RCC raft foundation is provided considering the vibration of the machines and uplift pressure.

To facilitate handling of equipments during the erection and maintenance periods, one electrically operated traveling (EOT) crane of 10 tones capacity is provided. To prevent the entry of floating material in the machines, trash rack is provided on the upstream of power house.

As discussed earlier, Semi Kaplan turbines with Siphon arrangement are proposed, in such an arrangement, when turbines are not in operation, during maintenance and shutdown period, entry of water in the turbines can be prevented by breaking the siphon effect. Hence, at the intake as well as at the draft tube outlet, gates are not provided, which results in saving of cost. Also, these turbines make possible to keep the level of the power house always above the highest water level, hence there is no risk of flooding of power house. The longitudinal section of power house is shown in Fig 5.

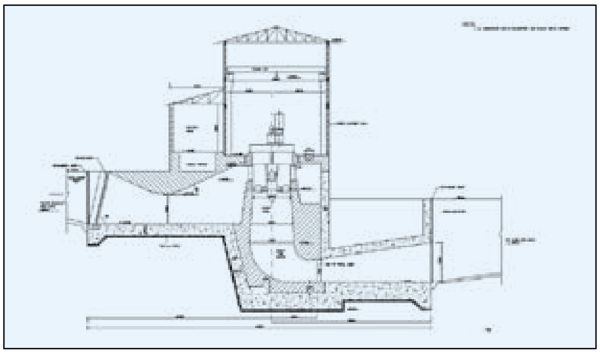

Fig 5 Longitudinal section of Power house

Tail race channel

About 172.0 m long tail race channel carries the water discharged from the power house to back to the Nadiad branch canal. The capacity, section etc. of tail race channel is kept same as that of power channel.

Approach road

A 4.5 m wide approach road is proposed on the left bank of channels to reach power channel, power house building area and tail race channel.

Electro-Mechanical Works

Hydraulic turbine

As discussed, two no.s of Vertical Semi Kaplan turbines with siphon intake are found most suitable, the details worked out are as follows.

Rated design head (Net Head) : 2.3 m

Rated discharge : 22.56 cumecs

Rated speed : 86 rpm

Rated specific speed : 746.45 (metric)

Runner diameter : 2870 mm

Governor

Two nos of computerized PLC based digital electronic governor are proposed.

Speed increaser (Gearbox)

The speed increaser will increase the speed from 86 to 430 rpm, which will result in reduction in size of generator and hence the cost.

Generator

Two no.s of vertical shaft Synchronous generators of 400 kW each, 3 Phase A.C., 50 Hz frequency are to be used. The other features are as follows:

Rating : 500 kVA

Generating Voltage : 415 V

Power factor : 0.8

No. of Poles : 14

Speed : 430 rpm

In this case, though Synchronous generator is proposed, an Induction generator may also be used to reduce the initial cost but in that case reactive power is to be taken from the grid, which is not desirable as the grid is weak.

Transformer

For stepping up the generating voltage from 415 V to 11 kV, two no.s of step up, 500 kVA, 3 phase, 50 Hz, 415 V/ 11 kV transformers are proposed. Transformers will be provided with controlling breakers on 11 kV side.

11 kV Switchgear (Vacuum Circuit Breaker)

12 kV, 630 A, 16 KA for one second, indoor type vacuum circuit breaker will be used. It will be suitable to be housed inside the powerhouse. Metal clad switch gear complete with CTs, PTs, over current

and earth fault protection, metering system shall be provided. The control switches, terminal boards, indicating instruments shall also be provided on this panel. It will be equipped with electrically and manually operated mechanism. It shall also have trip free mechanism.

Interconnection with grid

The power will be interconnected with Gujarat Power grid System at existing 132 kV/66 kV/11 kV substation of Madhya Gujarat Vij Company Limited (MGVCL), about 1.5 km away on its 11 kV bus by an 11 kV overhead line.

Construction Planning

The construction program has been so planned that design of works, finalization of tenders, all the civil engineering works and electromechanical equipments procurement and erection, testing and commissioning will be completed in 24 months. Construction schedule prepared for various works in the form of bar chart is shown in Fig 6.

Cost Aspects

Cost of the scheme is worked out in sufficient details so as to arrive at realistic cost estimate. The cost of civil works has been estimated based on quantities of different items of works. The basis of working out cost is as follows:

- Rates for various components of civil structures have been adopted as per the schedule of rates prevailing in the area.
- Provisions made for:
  - Establishment charges at the rate of 8 percent of the cost of works.
  - Audit and accounts charges at the rate of 1 percent of the cost of works
  - Losses on stock at the rate of 0.25 percent of the cost of civil works.
- Cost of Electromechanical equipment including turbine, generator, control panels etc. is based on prevailing rates.

Cost of generation per kWh of power depends on total annual generation and annual working expenditure. Ministry of New and Renewable Energy (MNRE), Govt. of India, provides subsidy for setting up Small hydropower projects up to 25 MW capacity [6]. Also, the Clean Development Mechanism (CDM) under the Kyoto Protocol to United Nations Framework Convention on Climate Change (UNFCCC) provides an opportunity for the power sector to earn revenue through the reduction of greenhouse gas emissions

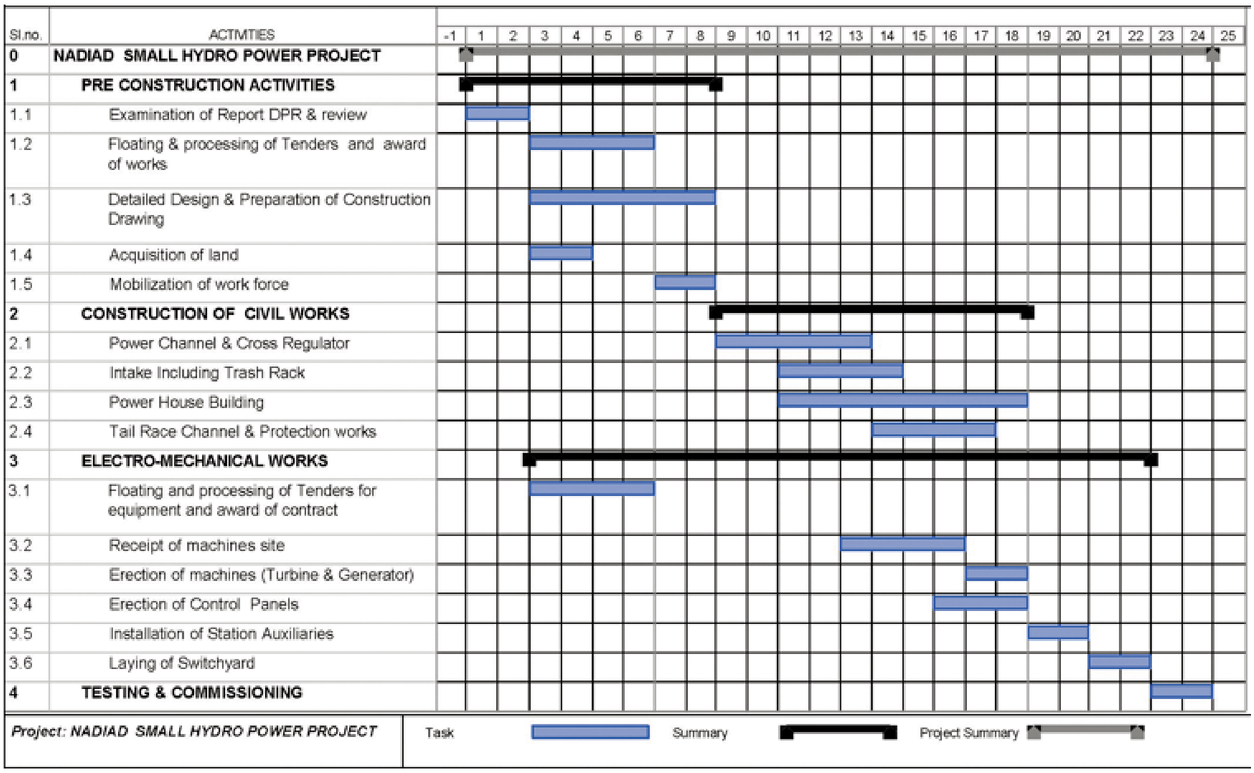

Fig 6 Construction Schedule

(GHG), particularly carbon dioxide (CO_2) [7]. The MNRE subsidy and CDM benefits are also considered. The basis of working out generation cost per kWh is as follows:

- The annual expenditure will consist of
  - Operation cost at the rate of 1 percent of works cost
  - Maintenance cost - at the rate of 1 percent of cost of civil works - at the rate of 2 percent of cost of electro-mechanical works
  - Depreciation charges-considering life of civil works and electro-mechanical works are as per standard norms given in the Gazette of India Extraordinary part -II section 3 sub section (ii) published by Ministry of Power and New and Renewable Energy, Dept. of Power, Govt. of India, vide notification No. 14155/2003 dated 29.07.2003.
  - Interest @ 12 percent per annum on capital invested as prevailing.
- As per MNRE policy, subsidy amount for such scheme is Rs 1.50 Crores x (Capacity in MW)$^{0.646}$ which comes out as Rs 129.86 Lacs.
- The CDM benefit are worked out on the basis of available Certified Emission Reductions (CERs) of 4195 for this project, based on annual energy generation of 4.56 MU. Taking sale price of CER as Rs 550 per CER (as prevailing), the CDM benefit comes out as Rs 23.07 Lacs/year.

Based on the annual power generation of 4.56 MU at 65% PLF as per availability of water, generation cost per unit is worked out, with and without MNRE subsidy and CDM benefits, as shown below.

Cost of project

Civil Works : 496.36 Lacs

E & M Works : 370.00 Lacs

Other Expenses : 128.64 Lacs

Total Cost : 995.00 Lacs

Installation Cost per kW : Rs. 1,24,375.00

Generation Cost per kWh : Rs 3.89

: Rs 2.94 (with MNRE subsidy and CDM benefits)

Conclusion

- Canal based schemes do not have uncertainties in terms of geology and hydrology. Also, they are easily approachable as they are in plain areas and do not have problem of power evacuation because they are near the load centers.
- The economic viability of the low head small hydropower schemes like canal based project is always difficult because of higher cost per kW compared to large units. Hence, it is very important that, enough care should be taken at the inception stage itself to have optimum design of small turbines.
- The proposed scheme shall provide the electricity perennially. Thus the scheme will be helpful in generating employment and improvement of quality of life in the nearby area.
- Considering increasing energy demand and rising electricity prices, the development of such low head scheme is quite favourable.

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