Economical and Environmental Effects of Pressure Reducer Valve Substituting by Small Hydro Power-Plants in Gravity Water Transmission Pipelines in Iran

Amir Bashirzadeh Tabrizi, Nassir Gifani

TOOSSAB Consulting Engineers Company
e-mail: bashirzadeh@hotmail.com , nssrgifani@gmail.com

***Abstract*-In this work, historical background of power generation by small hydro-power plants across the world and specially across the Iran with emphasis on small hydro-power plant using as recovery turbine in water transmission pipeline have been attended firstly, and then, three water transmission pipelines from Chah-nemie to Zahedan city, Shirindare dam to Bojnord city and Mokhtaran desert to Birjand city in Iran have been studied as case study samples. According to the sample pipeline characteristics and pipeline topography, reachable energy have been estimated; in the next step, attending to reachable energy, initial investment cost, total benefit of operating period, benefit to cost ratio and other economical parameters for small hydro-power plants in case study pipelines have been presented and power generation cost for same amount via other resources compared to the hydro-power cost. At the end, in agreement with environmental advantages of small hydro-power plants, the generated power using methods, proper solution for optimization of reachable energy in water transmission pipeline and substituting pressure reducing valve by small hydro-power plant in the pipelines as a major solution for energy recovering in water pipelines have been proposed.**

***Key Worlds*- Water Transmission Pipeline, Small Hydro Power-Plant, Reachable Energy, Renewable Energy**

1. Introduction

A short glance to the history of hydro energy using shows that the using of this energy renewable source had been attended differently; in 19 century, because of industrial progress, power generation from small hydro power-plant was attended but plenty and cheapness of fossil fuel resources, huge hydro potentials and solar energy, resulted to decreasing of small hydro power-plant using; in recent decades because of energy resource limitation, social impacts, environmental restrictions and long construction period of huge hydro power-plants, small hydro power-plants have been attended again. Existing of very galore hydro potential in energy consume zones(especially in villages), renewable energy resource remark because of its environmental advantages, short capital return, easy construction, long lifetime and low operation and maintenance cost are the main reasons of small hydro power-plant attending[1].

According to primal approximation, available hydro energy across the world is 2612000 MW which 5% to 10% of this amount comes from small hydro power. Utilization of small hydro power-plants is increasing across the world especially in areas which can not connect to the power transmission lines; for example, China is one of the pioneer countries in this issue; 76000 small hydro power-plants have been installed in China up to year of 1983 which generate more than 8500 MW. In table 1, the number of small hydro power-plants and their generated power amount in several European countries up to year of 2005 have been presented [2].

Table1. Small hydro power-plant numbers and generated power amount in several European countries

Country	Quan. of SHP	Total Power, MW	% in Total Hydro-power Production	% in Total Power Production
Germany	6200	1500	17	1.3
France	1730	2000	8	1.8
Austria	1700	866	8	5
Italy	1510	2230	11	3
Spain	1106	1607	9	3
Denmark	40	11	100	0.1
Netherlands	3	2	2	0.01

When the civil work and its cost are minimal, the small hydro power-plant installation is attended such as:

-Power-plant installation in existing dams.
-Power-plant installation in transmission pipelines.
-Power-plant installation in channel.

The small power-plant idea is attended in cases which water flux or other liquid flux like swage has been existed and also a proper head is reachable.

According to site physical condition, power-plant unit may has vertical, horizontal or crisscross shafts; in general case, there is not any differences between control equipments of unit with horizontal shaft and vertical shaft and the required equipments completely related to the project operating conditions[3].

In some gravity water transmission pipelines, the total available potential energy is not needed for water transmission and surplus of the available energy is damped by energy damper equipments such as pressure reducer valves or needle valves; in such water transmission pipelines, the small hydro power-plants can be used to recover surplus energy and supply the required power of pipeline equipments or village demands of pipeline path.

Hydro power-plants according to their capacity are divided to micro, mini, small and huge categories; however, there is not a general agreement about the classifying but the attended limitations in hydro power-plant classifying are so close to each other. As an example, Hydro power-plant categories according to IEEE standard are as follow:

Mini/Micro hydro electric power plant: units with external power less than 100 KW are called mini/micro hydro electric power plant.

Small hydro electric power plant: units with external power less than 5 Mw are called small hydro electric power plant.

Small hydro power-plant equipments can be classified in two general categories:

-Major Equipments: These equipments are related to power generating and transmission such as: turbine, generator, stimulation system, load control system, governor and trances.

-Auxiliary Equipments: it is called to the equipments which support the major equipment operation such as: unit control equipment, protective systems and internal utilization systems.

Small hydro power-plant turbines can be chosen from any of commercial turbines, but in a general classifying, hydro-turbine is divided to reaction and impulse turbine that both of them have different commercial samples.

2. Studied Water Transmission Pipelines

2.1. Water Transmission Pipeline from Shirindarre Dam to Bojnord City

The length of the pipeline is 47 Km and the pipe material is steel and fiber glass; it transfers 950 lit/s of raw water and because of water transferring through high elevation mountains with altitude of 1367m, water is transmitted by four pump stations. According to the pipeline patch topography, after the highest point of the pipeline patch which is the water treatment plant location, a part of reachable energy is used for gravity water transferring via the pipe with diameter of 700 mm and about 120 meter of elevating head is left which can be used for power generating.

2.2. Water Transmission Pipeline from Chah-nime 3 to Zahedan City

The pipeline patch from Chah-nime 3 to Zahedan has 192 km length and the diameter is 900 mm. The material of pipe is steel and pipeline crosses from different geography areas. There are four pumping stations which transfer 850 lit/s of raw water. In last stage of the patch, from equalization reservoir to water treatment plant with length of 28 Km, water is transferred by gravity force. According to equalization reservoir elevation(1546m), water elevation in water treatment plant inlet(1439m) and dynamic head loss of the pipe in this section (about 45 m), almost 60 m of reachable water head for power generating in inlet water treatment plant is available which is damped via needle valves, now.

2.3. Water Transmission Pipeline from Mokhtaran Desert to Birjand City

The pipeline passes from Rekat valley in Bagheran Mountain and with 68 km of length transfers 300 lit/s of water from Giv wells to Birjand city reservoir via steel, ductile iron and fiberglass pipes. In this pipeline patch, water is pumped to equalization reservoir by two pumping stations; after equalization reservoir up to the city service reservoir in elevation of 1740m , because of high slop of the patch, using of pressure reducing reservoir is necessary. Water is transmitted from equalization reservoir to pressure reducing reservoir via 500 mm diameter steel pipe by gravity; the length of the section is 6 km. The flow rate of the line is controlled by a needle valve which has been installed in pressure reducing reservoir inlet.

According to equalization reservoir elevation, pressure reducing reservoir elevation and the pipe head loss, 230 m of water head is reachable for energy recovering.

3. Reachable Energy

Estimation of energy generating potential for a location or power-plant installation capacity is the most important issue in hydro power-plant investment which is calculated by following equation:

$$P = \rho.g.Q.H.\eta / 1000 \qquad (1)$$

Which *P* is mechanical power at KW, ρ is water density which equals to 1000 kg/m^3, *g* is gravity acceleration which equals to 9.8 m/s^2, *Q* is pipeline flow rate in m^3/s, *H* is net water head in meter and η is total efficiency of generator and turbine which results from multiple of generator efficiency *(η_{gen})* and turbine efficiency *(η_t)*, therefore:

$$P = 9.8Q.H.\eta \quad (2)$$

In average, the value of η_{gen} and η_t are 0.95 and 0.90 respectively; η is equal to 0.855 and equation (2) changes to simple following form:

$$P = 8.38Q.H \quad (3)$$

Attending to equation (3), flow rate and net head are two important factors in energy generating; in small hydro power-plant which installed in water transmission pipelines, usually the head and flow rate is constant in every station. According to equation (3), the power-plant capacity for every of studied pipelines are as following:

Power-plant installation capacity in Zahedan water transmission pipeline:

$$P = 8.38*0.85*60 = 427KW$$

Power-plant installation capacity in Bojnord water transmission pipeline:

$$P = 8.38*0.95*120 = 955KW$$

Power-plant installation capacity in Birjand water transmission pipeline:

$$P = 8.38*0.30*230 = 578KW$$

4. Economical Evaluation

In small hydro power-plant evaluation, cost and income of the plan, capital return time, generated power value and capital internal efficiency rate, are final indicator for complete comparing of different components; to price estimate of energy unit generated by small hydro power-plant, initial investment cost is one of the main effective elements which should be determine properly.

Initial investment estimation of small hydro power-plant have been done based on economical calculation of several operating power-plants, study of more than 100 small hydro power-plants and different country experience; average initial investment cost of small hydro power-plants in north American and east Asian countries can be calculated by equation (4)[5].

$$C_k = K(P.H^{-0.3})^{0.82}\$ \quad (4)$$

Where, C_k is total initial investment cost of small hydro power-plant based on US dollar, P is the plant capacity in KW, H is the plant head in meter and K is an experimental coefficient which be resulted from small hydro power-plant execution in north America and equals to 22200. Because, the civil work cost differs in different countries, to estimate the civil work cost in different countries related to base country, the proper coefficient is used which its value is 91% of American value in Iran and 60% for East-Asian countries [5]. In addition, following elements, also affect the final price of small hydro power-plants in different countries; access rate, labor cost, geographical condition, material cost, dollar exchanging rate and transportation cost are the components which can result to some variations in final cost.

According to the above parameters, equation (4) changes to following equation:

$$C_k = L.K(P.H^{-0.3})^{0.82}\$ \quad (5)$$

Which, L is 0.7 for East-Asian countries [5]. Therefore, according to equation (3) and (5), the average total cost of small hydro power-plant in Iran can be estimated by equation (6) [5].

$$C_k = 91449(Q.H^{0.7})^{0.82}\$ \quad (6)$$

Where, C_k is total cost of civil work and electro-mechanical equipments in US dollar, Q is flow rate in m^3/s and H is net head of water in meter. By attention to power price in Islamic Republic of Iran annual budget (2008-2009) which is 0.084 $ for each kilo-what-hour of power and 25 year operation for small hydro-power plant, the benefit to cost (B/C) ratio of every attended power-plants can be calculated; Table 2 presents the estimated cost of initial investment, operation, income cost and B/C ratio for three proposed power-plants. Because these power-plants will be installed in water transmission pipelines and with the assumption of pipeline working in the whole year, the small power-plant can work in the whole year too but, it is intrinsic that the plant needs the time for service and maintenance. By attention to the this fact that the overhaul time of small hydro power-plant usually is low, the total time which the plant will not work is about 5 weeks per year(the time that the plant will not work because of water transmission pipeline accident is not attended).

Table2. Estimated cost for proposed power-plant (*10^6 $)

Cost	Zahedan	Birjand	Bojnord
Power-Plant Investment Cost (Electro-Mechanical Equipments & Civil Work)	839	773	1369
Annual Operation Cost of Electro-Mechanical Equipments	32	29	53
Annual Operation Cost of Building	6	6	9
Generated Power Annual Income	284	384	635

Interest Rate (%)	8	10	12	8	10	12	8	10	12
Operation Cost of Electro-Mechanical Equipments for 25 Years (present worth)	341	290	251	306	260	225	570	458	419
Operation Cost of Building for 25 Years (present worth)	64	54	47	64	54	47	96	82	71
Total Cost (present worth)	1245	1184	1137	1143	1087	1044	2035	1936	1859
Total Income of Generated Power for 25 Years(present worth)	3032	2579	2228	4105	3490	3016	6782	5767	4983
B/C Ratio	2.44	2.18	1.96	3.59	3.21	2.89	3.33	2.98	2.68

Figure 1, 2 and 3 shows relationship between initial investment with available head, initial investment with pipeline flow rate and B/C ratio with power-plant capacity respectively.

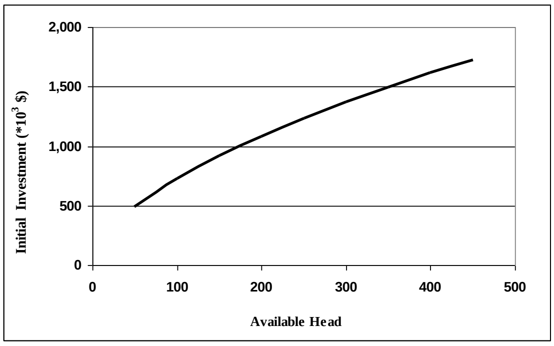

Figure1. Initial investment versus available head (flow rate 0.5 m3/s)

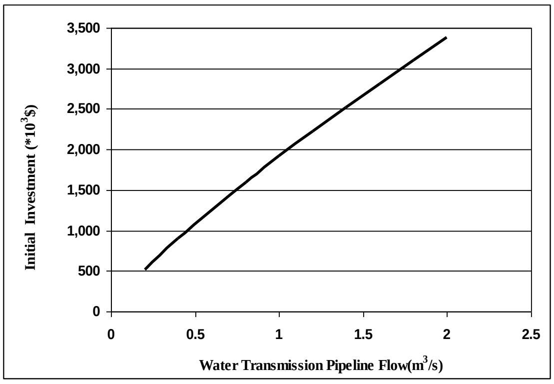

Figure2. Initial investment versus flow rate (available head 200 m)

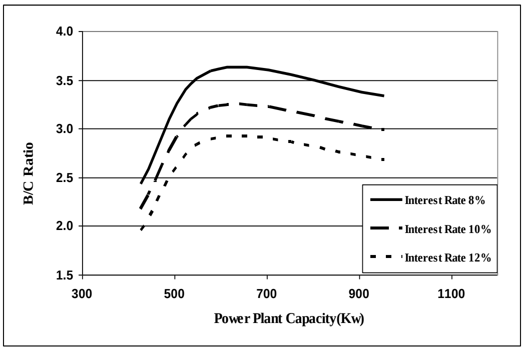

Figure3. Initial investment versus power-plant capacity

5. Substitute Energy Cost

In this section, substitute of proposed small hydro power-plant in Bojnord, Zahedan and Birjand pipelines by diesel generators which have the same power have been studied and analyzed economically. Because in most of the cases, small hydro power-plants use in the situation such village areas which can not be supplied by power network because of economical reasons , the power generation by diesel generators has been attended as substitute method[6]. Provided data in table 3 have been used as basic data for economical evaluation of diesel generator [7].

Table3. Basic data for economical evaluation of diesel generator

Diesel Generator Initial Investment Cost	200$ per KW
Conversion Rate	2.8 kwh per Liter of Diesel
Diesel Cost	0.5$ per Liter

Table 4 shows, estimate cost of initial investment, operation and fuel consumption in 25 year operation period for substitute of proposed small hydro power-plant in Bojnord, Zahedan and Birjand pipeline by the same power diesel generators (assume 5 weeks per year for generator overhaul).

Table4. Estimate cost for substitute of proposed power-plants by the same power diesel generators (*10^3 US$)

Cost	Zahedan			Birjand			Bojnord		
Diesel Generator Initial Investment Cost	85			116			191		
Fuel Annual Cost	604			817			1351		
Operation Annual Cost	4			6			10		
Interest Rate (%)	8	10	12	8	10	12	8	10	12
Fuel Cost for 25 Years (present worth)	6447	5482	4736	8726	7420	6411	14417	12260	10593
Operation Cost for 25 Years (present worth)	46	39	330	62	52	45	102	87	75
Total Cost(present worth)	6557	5606	4855	8903	7588	6572	14711	12538	10859

In figure 4, final cost of supply, installation, construction and 25 year operation (present worth) for proposed small hydro power-plants and same power diesel generators have been compared. Also, figure 5 shows, final capital cost difference of small hydro power-plant and diesel generator versus generated power for different interest rates.

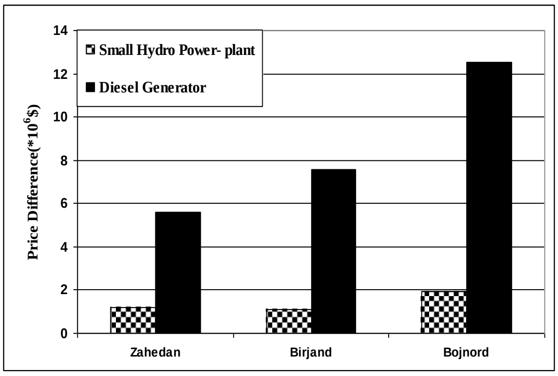

Figure4. Final cost of establishment and 25 year operation of proposed power-plants and same power diesel generators (10% of interest rate)

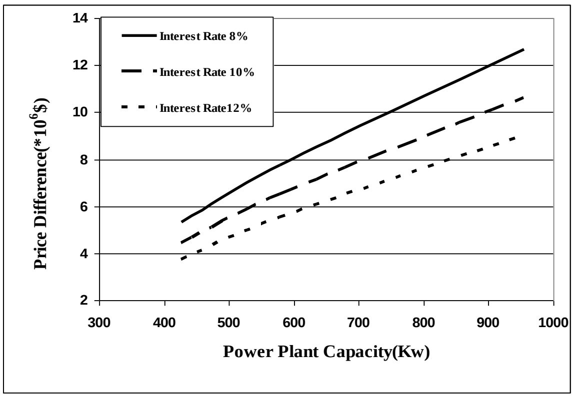

Figure5. Final capital cost difference of small hydro power-plant and diesel generator versus generated power for different interest rates (25 year operation)

6. Environmental Advantages of Generated Power by Small Hydro Power-Plant

Today, the wind turbines and small hydro power-plants can have the important role in renewable energy generation; in the other hand, energy generation by small hydro power-plants doesn't result to CO2 emission and other environmental pollutions [8].In fact, small hydro power-plants are so famous as stable and safe resources of renewable electrical energy; in additional, small hydro power-plants don't need to huge water dam or huge water reservoir construction and affect the environmental cycle of installation location so lightly[9].study of water transmission pipelines in Iran, shows that using of pressure reducing valve in gravity pipelines for surplus energy damping is a very usual method; with substituting of small hydro power-plant in gravity water transmission pipelines, energy recovery is reachable and the power can be supplied to the villages of the pipeline patch. Also, most of the water transmission pipelines in Iran transfer the surface water which finally enters to the water treatment plants and usually, in most cases, because of pipeline patch topography the water treatment location and best location for small hydro power-plant installation are so close to each other[10]; therefore, supply of water treatment plant power demand by installed small hydro power-plant in pipeline patch is the other usage of the generated power which can be attended deeply[11]. As an example, in water transmission pipeline from Chah-nime lake to Zahedan, the proper location for power-plant installation is in water treatment plant entrance and the plant demand is 500 Kw; for the water transmission pipeline from shirindare dam to Bojnord, the distance between right location of power-plant installation and water treatment plant is about 3 Km and water treatment plant power demand is 550 kw; in both cases water treatment plant power demand can be supplied by installed power-plant in the water transmission pipeline easily.

7. Conclusion

Study of small hydro power-plant history, shows that using of this kind of power-plant as one of renewable energy resources is increasing. In the other hand, as it was presented in economical evaluation section, the B/C ratio of small hydro power-plant establishment for all studied cases is more than two and figure 3 presents, the B/C ratio increases by net available head increasing of the plant(Birjand water transmission pipeline); Because of the low initial investment cost and slight operation cost of small hydro power-plants, their installation at water transmission pipelines in most of the cases, even in low installation capacity is economical. Also, small hydro power-plants are the safe and stable sources of electrical energy generation which with light impact on environmental cycles are clean electrical energy generators. Therefore, substitute of pressure reducer valves, which used in gravity water transmission pipelines widespread, by small hydro power-plants, can be resulted to huge amount of energy recovering; therefore, small hydro power-plant using in gravity water transmission pipeline designing should be considered technically and economically by consulting Engineers Company, seriously.

8. References

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