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Optimization Technique in Small Scale Hydro Power for Rural Area Electrification

Somila Hashunao
Dept. of Electrical Engineering
(Ministry of Human Resources Development, Govt. of India)
NERIST
Nirjuli, Arunachal Pradesh, India

Ritngenlang Sohshang
Dept. Of Electrical Engineering
(Ministry of Human Resources Development, Govt. of India)
NERIST
Nirjuli, Arunachal Pradesh, India

Ram Krishna Mehta
Dept. Of Electrical Engineering
(Ministry of Human Resources Development, Govt. of India)
NERIST
Nirjuli, Arunachal Pradesh, India

***Abstract*—The life style of well-being are define by consumption of electric load. Electricity play major setback both on economic as well as social well-being. Micro Hydro Power as cost effective and eco-friendly, is a magnolious tactic in deploying local natural sources for power such as from small scale rivers and streams. The turbine can run with or without the reservoir, usually fetch from run-off-river type. The flowing water strike directly into the turbine and then water flow down the stream without effecting the cycle of the system which in return gave minimal impact to the environment and maximum benefit to the surrounding where grid connectivity might not be recommendable due to its various cons. In many isolated remote area with few population grid connected has a major drawback on cost. So exploring more on locally available renewable resource will bring a wider prospect in terms of economical as well as maximum beneficial.**

In order to recapitulate the optimization hurdle of Micro Hydro Power plant a python programming has been done with a single objective function taken into account valuation of the plant as the fitness function (minimization problem).

Keywords—Renewable Energy, Optimization, economical.

INTRODUCTION

In present-day fast advance and developing world, as a result of the increase in environmental interest there is an obligation in harnessing energy from renewable and alternative sources of energy. The energy consumption in India is symbolized by low per capita level and a large divergence between urban and rural areas [1]. With the population round off to 40 crore people in India, out of which 47.5% of those living in isolated regions, are inaccessible to electricity [2]. The All India Installed capacity as on 31-032020 is 370047.97 Mega Watt [3], but as per the estimation by the government, India would require about 800,000 Mega Watt of installed capacity by 2031-32 [4]. It is estimated that India population can go beyond 1.6 billion by 2040 and ultimately would leads to increasing energy need by 2.7-3.2 times between years 2012 and 2040 [2]. Addition of such a bulk generation of electricity capacity becomes a heavy task for the country in the decades to come, hence, there is a need to harness/exploit energy from available sources in order to meet the demand as energy generation coming from coal, oil, and natural gas are limited/depleted type of resources which contributes to environmental pollution when burned and hence adds to global warming. With growing advancement of renewable energy technologies, assisted by the reduction in their costs and upon several environment scrutiny, the Government has already enunciated its resolution to raise the Renewable Energy capacity. Whilst a cumulative capacity target of 175 GW has been stated for the year 2022, by 2040 a fair capacity of 597710 GW is predicted to be accomplished [5]. Renewable energy is environmentally friendly energy that derives from inexhaustible resources, for instance wind energy, solar radiation, and hydro energy [6]. Renewable energy partakes 23.39% in the total installed generation capacity in the country, that is 368.98 GW (Up to 29th February, 2020) [7]. It has indicated that round the globe, that hydroelectric power stations allocates about 16 % of electrical power among the accessible renewable sources [8]. Therefore, small hydro power plant is a substituting source for the generation of electricity so as to subdue the energy deficiency. India is blessed with ample hydro power capacities hencing placing it in the fifth position in the world [9]. Ministry of New and Renewable Energy of the Government of India has been given with power and control for this development [7]. MHPP is an extremely competing and reliable alternative for electrifying far and remotest area over the lifespan of the system. Also SHP/MHPP can aid in the reduction of CO2 emission by alternative sources of energy that is established on fossil fuel [10]. It also adds to privation relief and life style improvement in rural and isolated parts of the region. Overall PHP and MHP technologies are paid special attention on electrifying an un-electrify areas of India where grid connection is not feasible, while mini and small hydro are usually connected with the grid. Pico, Micro and Mini hydro schemes can be of with or without construction of dam but most of run-off type [11]. MNRE is reinforcing the exploitation of small scale hydro project/ schemes either collective or on individual sector as it is concentrated in reducing the price of equipment’s, boosts its reliability and establish projects in fields that provides the maximum advantages in terms of application of energy capacity [11].

Given the envisaging and unchanging projections [12], hydro power plants indicate an efficient, suitable choice for supplying of energy to rural and remote regions [13]. As, it is the most affordable option for off-grid generation [20]. In spite of all of these, there are however some difficulties faced by the standard settings of MHP installments. The restricted resources, along with deficiency of capable workforce, can leads to an inefficient use of available resources, with this aspect, the decisions associated to the layout of the plant and its most significant variables, are largely established on experience and expertise. In view of this, there is a need to investigate on the efficient design strategies which are important for guaranteeing the efficient use of resources without jeopardizing the limited resources.

1.1 Classification of SHP

In India small hydro power stations are classified as Small, Mini, Micro, and Pico as shown in Table 1.1 [7]. Small Hydro Power capacities in the country is calculated to amount about 21135.37 MW from 7135 locations and is changing up from time to time [7]. According to the estimations made MNRE, as of 31st March 2014, 997 projects totaling approximately around 3803.7 MW has been carried out, also about 254 projects totaling approximately around 895.4 MW are still undergoing implementations [7]. Hence, closely about 3/4th of the capacities are yet to be tapped. Majority

SHPs stations are focused in the region of Himalaya and North–East particularly Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh. In the plain region Maharashtra, Karnataka, Madhya Pradesh, Chhattisgarh, Kerala and Andhra Pradesh, have considerable capacities.

Table 1.1: Classification of Small Hydro Power Plants [7]

Sl.no	Type	Plant potential (In KW)
1	Pico/watermill	<= 5
2	Micro	<= 100
3	Mini	101 to 2000
4	Small	2001 to 25,000

1.1 Working Principle of Small Hydropower/ Micro Hydro Power Plant

Micro hydropower operates on the same fundamental principle as that of a large hydro system which utilizes the potential of flowing water to produce mechanical energy in the turbine and finally converted into electrical energy by the use of generators. MHPP is "run-off river" type and does not require pondage or reservoirs, rather any barrier or dam is rather small, generally only a weir and small or no water is reserved. Flowing water has been split from the main river for creating a head which is allowed to pass over a pipeline with eminent energy. Pressurized water in the pipe hits the turbine and rotates the runner buckets and subsequently spins the shaft which is directly coupled to rotor of the generator Fig.2.1 shows a schematic representation of an MHPP

The numerical formula for electricity production of a power plant is as given below:

$$P=\eta\rho gQH_g$$

Where:

P: Electrical power produced η: Efficiency of the system (In the range of 60-80%) ρ: Water density (Normally 997 Kg/m^3) g: Gravity constant (m/s^2) Q: Water flow rate (m^3/s) H_g: gross height (m)

1.3 Components of MHPP

Hydropower stations are eco-friendly, renewable energy sources which transforms the pressurized energy of water into electrical power. The water from the turbine can then be used for other purposes like irrigation etc. The water head is applied for spinning the rotating component, converting the stored energy into macroscopic energy which then rotates the bucket of the turbine and ultimately generates electrical stream every time. Moreover, affordable controlling equipment's needs be applied for equalizing the input of water flow into the intake [14].

2.2 Water Head and Flow

The water head (H) & flow rate (Q) are two main components in any hydropower system as these two factors will determine the power capacity of a particular location. Head indicates the water pressure typically, the water head (H) denoted in terms of m (meter) or pressure (N/m2). Table 2.2 shows class of small hydropower as per head.

Table 2.2: Class of small hydropower station based on head [13]

Class	Head range (in m)
Low head	<10 m
Medium head	10-50 m
High head	>50 m

2.3 Penstock

The Penstock or pipeline directs the water coming from the dam and leads it to turbine. The water in the pipe contains potential energy since the water height leads to formation of kinetic energy due to the flow of water [15].

Power equation shows that the overall amount of power produced by the MHPP plants is dependent upon the quantity of water discharge (Q) via the pipe and also on the water head (H) of the reservoir.

2.4 Turbine

The turbine is the core or the heart of the MHPP system. It spins the shaft and in turn drives the electrical generator in MHPP as the shaft of turbine and rotor of

power. The schematic representation of a typical Micro Hydro Plant station and its main components is represented in fig 1.

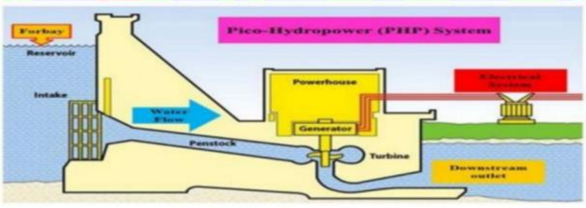


Figure 1: Schematic presentation of a MHPP system [14]

2.1 Forebay/upstream source

It consists a pondage, gate or intake, trash rack, overflow etc. Gate/Intake is where water is split from the mainstream. It is important to note that the intake should be able to withstand fluctuations or disturbances within the main water

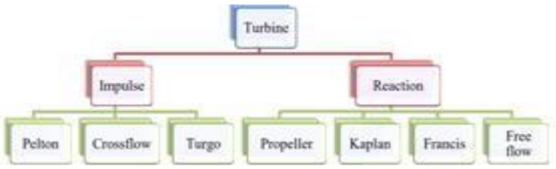


Figure 2: Types of turbine [16]

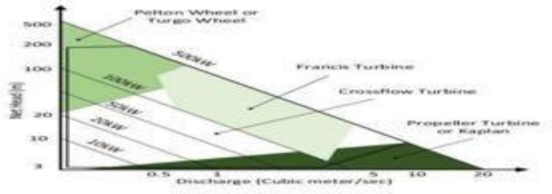


Figure 3: Choosing the type of turbine according to the head and flow Rate

generator are directly coupled. In the process of which flowing water hits the blades of the turbine, the potential and kinetic energy are being converted to mechanical energy. The rotational movement of the blade spins the shaft, and in turn spins the rotor of the electrical generator. Hence, Proper choice of the turbine is crucial for exploiting the maximum amount of energy and also to optimize the cost of the plant. Turbines can either be impulse or reaction turbine. The type of turbine denotes the fashion in which the water drives the runner of the turbine to rotate. Reaction turbine works with their runners fully immersed and builds up a torque due to the reaction of water pressure against the blade of the runner. Impulse turbines operates with their runner in air and transform potential energy of flowing water into kinetic energy of a jet that pushes into the buckets of the turbine so as to develop a torque.

2.5 *Turbine Selection*

It is crucial in opting for the right type turbine because mostly the losses incurred are due to the application of unsuitable turbine. There are many criteria for the selection of turbine which includes the Net water head, fluctuation of discharge of water flow passing via the turbine, generator speed, cavitation problems, and price of the turbine. Net head is the most essential condition and needs to be reckoned while choosing the type of turbine. Fig 3 shows the variation of turbine head with discharge.

2.7 Generator and Power house

The electrical generator converts the mechanical or rotational power from the turbine shaft into electrical power. In MHPPs, there are mainly two types of generators used for the conversion of mechanical power into electrical i.e asynchronous generator and synchronous generator. Synchronous generators Induction generators produces AC power.

Induction generators are generally preferred in isolated or remote areas as they they are robust and most reliable. The type of generator chosen for the MHPP systems includes the following aspects: (i) The MHPP's generator approximated power (ii) The type of electrical loads i.e AC or DC (iii) Economically attainable generating capability (iv) Low Cost generator.

The powerhouse is a building component that houses the generator, turbine and other major equipment's. It should be located as low as possible so as to raise the system head and the output power. Nonetheless, it has to be higher than the reservoir level for protecting the electrical devices against water overflowing.

2.7 Electrical system

This system includes an electricity transition system, electrical controller, and electrical loads. It modifies the supply of generated power to the loads by halting changing voltage. Type of load connected to the MHPP depends chiefly upon the amount of generated power.

3. Methodology

Standard Design Process of Micro Hydro Plant MHPP design is normally branched as given below:

i. Assessment of useable water flow rate, Q

ii. Assessment of useable height/head, Hg.

iii. Decision making for locating powerhouse and dam.

iv. Evaluation of generated power, P. v. Sizing of the machinery

Assessment of feasible water flow and head embodies the valuation of the potential of the water resources. Erstwhile Q and H has been calculated, locating the powerhouse and dam are opted by the professionals on the ground of site visit and expertise. The resolution is concentrated on minimizing penstock length L, since this parameter will greatly perturb the price and ultimately the final functioning of the plant. An evaluation of the produced power can be calculated using equation (1).

Although the customary techniques involve an economic, robust strategy for the layout of the plant, it is however important to mention that considerable condition of it can be enhanced for accomplishing an improved application of the resources without negotiating neither the profits of the technique nor its modesty.

3.1 Problem Statement

The aspects that makes up a general MHPP plant can be divided into two main unit's i.e. the piping and the powerhouse. Although water storage is not frequently used in MHPPs, a small reservoir is usually equipped for the reason of providing an easy passage to the pipeline, hence losses due to friction and entry of air are irrelevant. Positioning of these factors determines the maximum obtainable energy, corresponding to the gross height, Hg, this is depicted in figure 3.1.

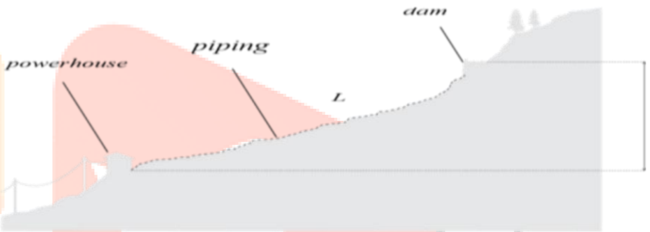


Figure 3.1: River profile scheme

3.1 System Model

The model is created by the gross head H_g *and* flow rate of water Q, where the pertinent design variables can be expressed. The power generated, *P*, and the cost of the plant, *C are the required parameters for analysis*.

3. Water flow and obtainable power

The Power available for the plant, *P* can be expressed by the water flow *Q* and the net head h [20], as follows

$$P = \eta \rho g Q h \qquad (1)$$

h: net height at the entrance of the turbine

ρ: the water density *g:* the gravitational constan*t* *η* :global efficiency; $\eta = \eta_t \eta_g$

The net head differs from the gross height, H_g, by means of the friction loss h_L along the penstock, due to the non-ideal behaviour or the inner walls of the pipes. Hence,

$$H = Hg - hL \qquad (2)$$

Assuming an impulse turbine, the net head at the entrance of the turbine, the water head at the nozzle, h, is entirely transformed into kinetic energy, so it can be expressed in terms of the flow, Q, as

$$H = \frac{1}{2gS_{noz}^2} Q^2 \qquad (3)$$

h_L, can be expressed [20] as the sum of distributed losses in the pipes (due to the friction through the pipe) and the concentrated losses (due to friction in the n_c pipe elbows and the nozzle),

$$h_L = [f\frac{L}{D_P} + n_e k_e (\frac{S_P}{S_{noz}})^2] \frac{Q^2}{2gS_p^2} \qquad (4)$$

S_p D_p and L are the cross sectional area, the diameter and the length of the penstock respectively. The constants f, K_c and K_{noc} represent the friction losses coefficients due to: the pipe roughness, the pipe elbows, and the nozzle respectively. It can be proved [21] that

$$f\frac{L}{D_P} >> K_c n_e + k_{noz} (\frac{S_P}{S_{noz}})^2] \frac{Q^2}{2gS_p^2}$$

where

$$h_L = f\frac{L}{D_P} \frac{Q^2}{2gS_p^2}$$

Also

$$S_p = \pi D_p^4 /4$$

Therefore simplified expression of h_L is

$$h_L = K_p \frac{L}{D_p^5} Q^2 \qquad (5)$$

where constant K_p is expressed as

$$Kp = \frac{8f}{\pi^2 g}$$

Solving (5) and (3), we get

$$H_g = \frac{1}{2gS_{noz}^2} Q^2 + k_p \frac{L}{D_p^5} Q^2 \qquad (6)$$

Writing Q in terms of H_g, we get

$$Q = [\frac{H_g}{\frac{1}{2S_{noz}^2} + k_p \frac{L}{D_p^5}}]^{1/2} \qquad (7)$$

Also, writing P in terms of H_g and L by using equation (7), (3) and (1), we get

$$P = \frac{\eta\rho}{2gS_{noz}^2} \frac{H_g}{\frac{1}{2gSnoz^2} + K_p \frac{L}{D_p^5}}]^{\frac{3}{2}} \qquad (8)$$

From equation (8) it can be infer that the water flow Q, the gross height Hg, and the penstock length and diameter, L and D_p respectively decide the generated power, which play a major role in design of an MHPP layout. Hence it is appraised as design variables for the plant in this work. With this successive, the issue will be constructed in a way that individual program defines a set of these variables, so that the execution of the plant and the fitness of the solution, can be effortlessly analyses.

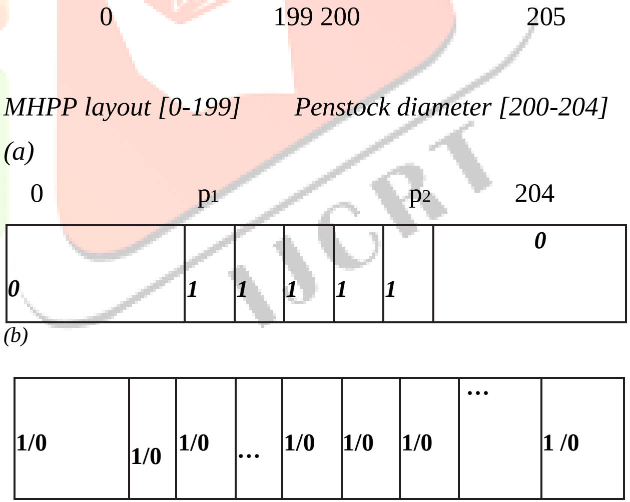
4. Single-Objective Optimization Problem

Algorithm 1, shows the approach to the optimization of a single objective problem. Initially it starts with arbitrary initial population P_i, which is estimated. Then, the offspring μ is generated by using the genetic operator crossover and mutation. Here, P_{cx} and P_{mut} refer to the crossover and mutation probability, respectively. Next, the offspring is evaluated, and the new population λ is determined from the offspring generated and the preceding population P_g. This approach guarantees a good level of elitism since parents and offspring compete with each other in order to be selected for the next generation [22]. Once the algorithm is over, the following population holds the optimum explication for the maximum function of the problem. Normally, the cessation criterion of the algorithm is a given by the number of generations.

```
Algorithm 1:: GA mupluslambda
1.   Create initial population Pi
2.   Evaluate Pi
3.   Pg=Pi
4.   While stop== False do
         Parents' selection
         Create Offspring μ (crossover  and mutation )
         Evaluate ;
     Select new population ;
     End
```

4.1 Individual Representation

Each individual render a feasible key for design or layout of the MHPP. Hence, the chromosome of each individual is a list consisting of ones or zeros (binary variables) according to equation (11) since there is a need to discretize hence represented in binary form. Each generation of the chromosome represents the placement of an elbow. In addition, pipes diameter is also included in the chromosome by means of a binary codification, presuming all pipes have the identical diameter. The initial 200 bits correspond to the discrete data are derived from the river profile (Figure 3.6 a). When the diameter is embedded in the chromosome, the last five bits represent the diameter D_p (see Figure 3.6 a). Using five bits, 32 decimal numbers can be represented. According to (8), D_p cannot be equal to 0, therefore the decimal numbers represented are within the interval {1 − 32}, which determine the value of D_p in centimeters. The minimum index containing one fit to the placement of the powerhouse (lowest position in the river profile) and maximum index containing one fit to the location of the water intake (highest position in the river profile). The initial population of the GA is generated randomly. The algorithm consists of selecting two random points p_1 and p_2 within the interval [0, S − 1], being $p_1 < p_2$, and filling up with ones the positions within the interval [p1, p2] (see Figure 4)



0	1	1	1	1	1	0

1/0	1/0	1/0	…	1/0	1/0	1/0	…	1 /0

Figure 3.6: (a) Individual representation considering the diameter of the penstock D_p. (b) individual generation scheme.

4.2 Fitness Function

The fitness of each individual is given by the cost function whose is represented by (9). Therefore, lower the cost, better is the solution. However, void solutions should be scarped so that they do not engaged in future generations of the GA. Death penalty is used to penalized invalid individuals. Hence, the fitness of each individual will be calculated as if **solution valid** F = (8),

else F = −∞, ∞, according to (14), (16)

4.3 Optimization of MHPP in Python

The application of the optimization module that is available in python is used. For this, the river profile is first discretized so that accordingly the optimization can be done. The modules used in the python code includes, numpy, random, scikit=optimization, scipy and matplotlib. The scikitoptimization has the attribute dummy minimization which is used in the code. It is a simple and efficient library for minimizing problems. the formulated optimization problem is proved for an arbitrary profile river.

An illustrated scheme includes a discretization of N = 200 points according to (10). Layout of Micro Hydro Plant was assumed to bestow a vague small clusters of houses, whose fundamental power demand is set to be 8 kilo Watt (Pmin). Water flow rate being 70 L/s (Q River), having 50% extraction allotment. Also, the diameter of the nozzle is 20mm and the internal diameter of the penstock is kept constant at 0.2m and friction coefficient is 9.96×10−4 [21]. Also, a corresponding price of 50 m is considered in the placement of the elbows, and attributes of the terrain allows placement of supports and excavations of up to 1.5 m.

5. RESULTS AND DISCUSSION

The problem in consideration is being tested for different cases depending on minimum power, elbow cost, maximum flow extraction rate, maximum support, and maximum excavation. The table 5 below shows according the parameters of the problem and the solution.

For evaluating the consequences of elbow equivalent cost λ, which is given by equation (9), the problem in question is firstly resolved by putting λ=0 (case a), and then worked out by putting λ=50 m (case b). Also for seeing the influence of support and excavation restrictions the assumptions considered high enduring burden of the terrain that is considered, which devise a low allowance for excavation because of the hindrance in delving, also a higher allowance for supports because of the terrain's high tip struggle. The problem is investigated by setting the support and excavation constraints to 3m and 0.5 m respectively, while keeping other constraints same. Also different case is investigated by putting these limits to infinity so that the restrictions in relation with supports and excavations are more significant in the optimization problem.

Table 3: Summarized table of problem parameters and its solution accordingly

	Problem					Solution				
Case	P_m (kW)	κ (%)	λ (m)	εsup (m)	εexc (m)	P (kW)	Hg (m)	L (m)	Q (m^3/sec)	C (m)
A	8.0	50	0	1.5	1. 5	10.212	231.25	1172.21	0.01485	31
B	8.0	50	50	1.5	1. 5	10.158	230.4	1171.94	0.0148	32
C	8.0	50	50	3	0. 5	10.157	230.4	1172.11	0.01483	30
D	8.0	50	50	Inf	Inf	10.10	225.02	1137.26	0.0148	25
E	20	50	50	1.5	1. 5	21.684	129.45	618.3	0.01909	234.73

Also, (case e) is studied with the use of the same variables that have been presented in case b, by putting a higher value of minimum power specification, P_{min}=20kW. The problems variables with their optimal solutions were represented in table 3.

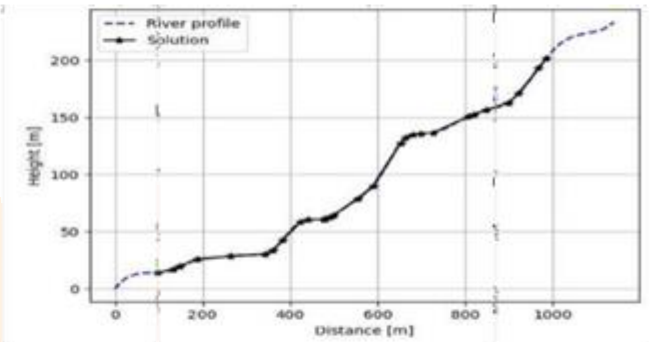


Figure 4.shows the optimal penstocks related to these solutions together with the profile of the river.

From the results, a few deductions can be made. For case (a), it can be noticed that by avoiding the elbow cost it doesn't illustrate an unreasonable number, this is because for individual couple of dam and turbine position, lesser elbows indicate long length of the pipe, and thus the lower the overall penstock length. Nevertheless, while fixing a positive equivalent cost of the elbows also determines optimum penstock location having much lesser number of elbows, thus involving rather long penstock also an eventually high cost (case b). With regards to the influence of a higher capacity endurance of the terrain, as was be noticed that the optimum installation was fairly distinctive from the former cases, that is reasonable, because the longer length of the pipe can be placed in hollow areas, as a result of high available supports, whereas bulging regions require a much high number of elbows being the cause of the stern excavation restraint. For case (d), in which there is no restriction of supports and excavations, the algorithm determines a much rather unique optimum penstock location with a lone length, as was anticipated. In view of this special case, the cost of the plant is rather less than that found with case (b) and case (c), thus optimum penstock is the shortest. Ultimately, optimal penstock of case b is the lengthiest, thus mostly costly/pricy, necessitating a much high number of elbows, as was anticipated as a result of high power demand.

6. CONCLUSION

An economical, sturdy penstock optimization problem of single objective function has been elaborated in this paper.
The problem helps in determining the optimal installation of MHPP, insuring a minimal supply of power, maximum utilization of water flow rate, considering that terrain's excavation and support have restrictions.

The objective functions can be effectively solved using computational methods one of which is Genetic Algorithm. The objective function can be considered into single objective problem wherein the fitness function is the cost (minimize) and a multi objective function wherein there are two fitness function i.e power (maximum) and cost (minimization). These can be studied by python coding with given constraints and parameter initialization.

REFERENCES

[1] CEA, Load Generation Balance Report 2019, (http://www.cea.nic.in/annualreports.html)

[2] MNRE, (https://mnre.gov.in/decentralized-systems)

[3] CEA,Oct 2019 Report, (http://www.cea.nic.in/monthlyexesummary.html)

[4] Planning Commission of GoI. Integrated Energy Policy 2006,

[5] Draft National Energy Policy NITI Aayog, Government of India

[6] Dr. S.K.Dave1, Ashok Kumar A. Parmar , Darshak K. Parmar. Small, Mini, Micro and Pico Hydro Power Plant: Scope, Challenges & Deployment in Indian Context. International Journal of Advance Engineering and Research Development Volume 2,Issue 3 (2015)

[7] MNRE SHP Program, (https://mnre.gov.in/smallhydro/currentstatus#energy)

[8] Shailesh Sharma, John Waldman, Shahab Afshari, Balazs Fekete. “Status, trends and significance of American hydropower in changing energy landscape” Renewable and Sustainable Energy Reviews, ISSN: 1364-0321, Vol: 101, Page: 112-122 (2019).

[9] Kumar A., Schei T., Ahenkorah A., Caceres Rodriguez R., Devernay J.-M., Freitas M., et al. Hydropower, IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. 2011. [10] Himanshu Nautiyal, S.K. Singal, null Varun, Aashish Sharma. “Small hydropower for sustainable energy development in India”. Renewable and Sustainable Energy Reviews, ISSN: 1364-0321, Vol: 15, Issue: 4, Page: 2021-2027(2011).

[11] Mukesh Kumar Mishra, Nilay Khare, Alka Bani Agrawal. “Small hydro power in India: current status and future perspectives Renewable and Sustainable Energy Reviews, ISSN: 1364-0321, Vol: 51, Page: 101-115 (2015)

[12] Al Irsyad, Muhammad Indra & Halog, Anthony & Nepal, Rabindra. “Renewable energy projections for climate change mitigation. An analysis of uncertainty and errors”. Renew. Energy 2019, 130, 536–546

[13] C.P.Jawahar, Prawin Angel Michael. “A review on turbines for micro hydro power plant”. Renew.Sustain. Energy Rev. 2017, 72, 882–887. [14] Abudukeremu Kadier, Mohd Sahaid Kalil, Manoj Pudukudy, Hassimi Abu Hasan, Azah Mohamed, Aidil Abdul Hamid. “Pico hydropower (PHP) development in Malaysia: Potential, present status, barriers and future perspectives”. Renewable and Sustainable Energy Reviews, ISSN: 1364-0321, Vol: 81,2796-2805(2017).

[14] Waqar Uddin, null Ayesha, Kamran Zeb, Aun Haider, Bilal Khan, Saif ul Islam, M. Ishfaq, Imran Khan, M. Adil, Hee Je Kim. Current and future prospects of small hydro power in Pakistan: A survey, Energy Strategy Reviews, ISSN: 2211-467X, Vol: 24, 166-177(2019)

[15] Water Turbine (http://waterturbines.wikidot.com/main:types-ofwaterturbines)

[16] “Guide to hydro power” An Introduction to Hydropower Concepts and Planning (https://www.canyonhydro.com/guide/Guide%20to%20Hydropower. pdf)

[17] ESHA. Guide on How to Develop a Small Hydropower Plant. 2004

[18] K. Deb, A. Pratap, S. Agarwal and T. Meyarivan. "A fast and elitist multi objective genetic algorithm: NSGA-II," in IEEE Transactions on Evolutionary Computation, vol. 6, no. 2, 182-197, April 2002,

[19] Arturo S Leon and Ling Zhu. “A dimensional analysis for determining optimal discharge and penstock diameter in impulse and reaction water turbines”. Renewable Energy, 71:609–615, 2014

[20] A. Tapia, P. Millan, F. Gomex-Estern. Integer programming to optimize Micro-Hydro Power Plants for generic river profiles. Renewewable Energy, Elsevier, 2018, vol.126(C), 905–914

[21] Alejandro Tapia Cordoba, Daniel Gutierrez Reina and Pablo Millan Gata. An Evolutionary Computational Approach for Designing Micro Hydro Power Plants. Energies, 2019, ISSN: 1996-1073.