Self Excited Induction Generator and Municipal Waste Water Based Micro Hydro Power Generation System

R. K. Saket and Lokesh Varshney

***Abstract*—This paper describes an alternative energy source: municipal waste water for micro hydro power generation. Reuse of municipal waste water can be a stable, inflation proof, economical, reliable and renewable energy source of electricity. A micro hydro photovoltaic hybrid power generation system has been designed, developed and practically verified to provide reliable energy to suitable load in the campus of the Institute of Technology, Banaras Hindu University, Varanasi (Uttar Pradesh) India. The hydro potential of the waste water flowing through sewage system of the university has been determined for annual flow duration and daily flow duration curves by ordering the recorded water from maximum to minimum flows. Several factors such as design pressure, the roughness of the pipe, interior surface, method of joining, weight, ease of installation, accessibility to the sewage system, design life, maintenance, weather conditions, availability of material, related cost and likelihood of structural damage have been considered for design of a particular penstock for reliable operation of the developed MHPS. Output power has been estimated for available different head and flow rate of the waste water. Various types of the turbine-generator sets for different available head have also suggested for reliable operation of the developed MHPS. Self excited induction generator has used and recommended for reliable operation the MWW based MHPS.**

***Index Terms*—Municipal waste water, flow-duration curve, self excited induction generator, sewage system, system reliability.**

I. Introduction

Micro hydro power system is one of the popular renewable energy sources in the developing countries. Most MHPS operate in isolated mode supplying the electricity in the local rural area where the population is very small and sparsely distributed. The extension of grid system is not financially feasible because of high cost investment required for transmission line. Small-hydro power systems (SHPS) are relatively small power sources that are appropriate in many cases for individual users or groups of users who are independent of the electricity supply grid. Although this technology is not new, its wide application to small waterfalls and other potential sites are new. It is best suited to high falls with low volume, such as occur in high valleys in the mountains. SHPS is the application of hydroelectric power on a commercial scale serving a small community and is classified by power and size of waterfall. A generating capacity up to 10 MW is becoming generally accepted as the upper limit of small hydro, although this may be stretched up to 30 MW in some countries. Small hydro can be further subdivided into mini hydro, usually defined as less than 1,000 kW, and micro hydro power system (MHPS) which is less than 100kW [1]. Hydroelectric power is the technology of generating electric power from the movement of water through rivers, streams, and tides. Water is fed via a channel to a turbine where it strikes the turbine blades and causes the shaft to rotate. To generate electricity the rotating shaft is connected to a generator which converts the motion of the shaft into electrical energy [2].

Micro hydro electric power generation system based on municipal waste water (MWW) is highly fluctuating in nature [3] and will affect the quality of supply considerably and even may damage the system in the absence of proper control mechanism. Main parameters to be controlled are the system frequency and voltage, which determine the stability and quality of the supply. In a power system, frequency deviations are mainly due to real power mismatch between generation and demand, whereas voltage mismatch is the sole indicator of reactive power unbalance in the system [4]. Reactive power balance in the hybrid system can be obtained by making use of variable reactive power device e.g. static VAR compensator (SVC) [5].

Comparisons of various penstock materials have been presented considering friction, weight, cost, corrosion, joining and pressure for reliable operation of the MHP system [2]. Long term effect of power system unbalance on the corrosion fatigue life expenditure of low pressure turbine blades and a new single pole switching technique for reducing tensional torques in turbine blades and shafts and enhancing power system stability in [6] – [7]. Hybrid power systems are the most attractive option for the electrification of the remote locations. There are problems however that keep them from being widely implemented. These include high cost because of the system complexity, site specific design requirements and the lack of available control system flexibility [8]. If a new generation technology is introduced that makes a relatively low contribution to the reliability of meeting peak demand then additional capacity may be needed to provide system margin, and a cost is improved on the rest of the system. Quantification of the system costs of additional renewable in 2020 has been presented [9].

A sewage micro hydro power system can be reliable and provide stable electrical energy. Micro-hydro power system using waste water from community neither requires a large dam nor is land flooded. Only waste water from different parts of the city is collected to generate power which has minimum environmental impact [10]. This alternative

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renewable power generation system has been appropriately designed, developed and implemented at Institute of Technology, Banaras Hindu University, Varanasi (India). The main objective of this project is to prevent the holy river Ganga from pollutions due to sewage / municipal waste water. To prevent the holy river Ganga, municipal waste water of the Varanasi city has been proposed for utilization for electric power generation. After proper chemical treatments of the municipal waste water, it is proposed to provide it to local farmers for irrigation purpose.

II. Selection of Basic Components for MHPS

The principal components of the micro-hydro power system using sewage system are sewage tank, penstock, turbine, generator for reliable operation of the system. Interconnection of the micro hydro and PV system for reliable operation of the hybrid plant has been proposed and designed at sewage station of the Banaras Hindu University, Varanasi, India. A tailrace and solar pump through which the water is released back of the sewage storage plant to maintain head of the water according to flow rate v/s duration curves is shown in the Fig. 1(a) and (b).

A. Selection of Penstock Pipe

The penstock is often the most expensive item in the project. Several factors should be considered when deciding which material to use for a particular penstock design pressure, i.e. the roughness of the pipe's interior surface, method of joining, weight; ease of installation, accessibility to site, design life, maintenance, weather conditions, availability, relative cost and likelihood of structural damage.

TABLE I: Comparison of Penstock Materials [3]

Sr. No.	Materials	Friction/ Weight	Corrosion	Cost/	Joining	Pressure
1.	Mild Steel	×××	×××	××××	××××	×××××
2.	HDPE	×××××	×××××	××	××	×××××
3.	uPVC	×××××	××××	××××	××××	×××××

×× Poor, ××× Average, ×××× Good, ××××× Excellent

The pressure rating of the penstock is critical because the pipe wall must be thick enough to withstand the maximum water pressure, otherwise there will be a risk of bursting. The pressure of the water in the penstock depends on the head, the higher the head, the higher the pressure. The most commonly used materials for a penstock are mild steel, high density poly ethylene (HDPE) and unplastified polyvinyl chloride (uPVC), because of their suitability, availability and approvability. The UPVC exhibits excellent performance over mild steel and HPDE in terms of least friction losses, weight, corrosion, and cost, etc. Comparison of the penstock materials [2] considering friction, weight, corrosion, cost, joining and pressure have given in the Table I. uPVC penstock pipe has been used at sewage power generation system due to listed advantages compared to others and has proposed for future work in this field.

B. Selection of Turbines

Turbine is connected either directly to the generator or is connected by means of gears or belts and pulleys, depending on the speed required for the generator. The choice of turbine depends mainly on the head and the design flow for the proposed micro-hydro power installation. The selection also depends on the desired running speed of the generator. Turbines used in the hydro system can be classified as Impulse (Pelton, Turgo and Cross flow), Reaction (Francis, Propeller, and Kaplan) and water wheels (under-short, breast-shot and overshot)[2]. Groups of the water turbine for various head available are given in the following Table II. Propeller Kaplan turbine has been proposed for low head available at sewage power generation system at IT-BHU, Varanasi (India).

TABLE II: Group of Turbines

Turbine Runner	High Head (more than 100m/325 ft)	Medium Head (20- 100m/60-325 ft)	Low Head (5- 20m / 16- 60 ft)	Ultra Low Head (less than 5 / 16 ft)
Impulse	Pelton Turgo	Cross flow Turgo Multi Jet Pelton	Cross flow Multi-Jet Pelton	Water Wheel
Reaction	-	Francis Pump-as-turbine	Propeller Kaplan	Propeller Kaplan

C. Selection of Generator

Induction generators are generally appropriate for micro hydro power generation [1]. Induction generator (IG) offers many advantages over a conventional synchronous generator as a source of isolated power supply [12]. Reduced unit cost, ruggedness, brush less (in squirrel cage construction), reduced size, absence of separate DC source and ease of maintenance, self-protection against severe overloads and short circuits, are the main advantages of IG [13]-[14]. Capacitors are used for excitation and are popular for smaller systems that generate less than 10 to 15 kW. All generators must be driven at a constant speed to generate steady power at the frequency of 50 Hz. The two pole generator with a speed of 3000 RPM is too high for practical use with micro hydro power system. The 1500 RPM, four pole genitor commonly used. Generator operates at less than 1000 RPM becomes costly and bulky and to match the speed of the generator to low speed of the turbine; a speed increasing mechanism such as belt and /or gear box is required. Output power has been measured at available different heads (minimum / maximum) and waste water flow rate. Type of the turbine-generator sets for different sewage water heads has been proposed in Table III for reliable operation of the MH power system using municipal waste water. Use of induction generator is increasingly becoming more popular in MHP application because of its simpler excitation system, lower fault level, lover capital cost and less maintenance requirement. However, one of its major drawbacks is that it cannot generate the reactive power as demanded by the load. Propeller - Induction Generator has been proposed for micro hydro power generation system at IT-BHU, Varanasi for reliable power generation.

TABLE III: INTEGRATED MICRO-HYDRO POWER SYSTEMS

Sr. No.	System	Power o/p (W)	Head(M) Min. / Max.	Flow (lps) Min./Max.	AC (V)	Type of Turbine/ Generator
1.	Ultra low Head	200-1000	1/5	35/ 130	110 V	Propeller; Permanent magnet AC Generator
2.	Low Head	800-5000	2/5	28/ 120	110 V	Propeller; Induction Generator
3.	Medium Head	200-500	5/12	6/10	110 V	Turgo; Permanent magnet AC Generator
4.	Medium Head	600-2000	8/17	20/ 30	110 V	Turgo; Induction Generator
5.	Medium Head	300-5500	12/ 34	5/28	110 V	Pelton; Induction Generator
6.	Medium Head	5000-8000	24/ 34	33/ 40	110 V	Turgo; Synchronous Generator
7.	Medium Head	9000-16000	24/ 34	66/ 80	110 V	Turgo; Synchronous Generator
8.	High Head	1500-5000	20/ 90	80/ 85	110 V	Turgo; Synchronous/ Induction Generator

III. SELF EXCITED INDUCTION GENERATOR: AN OVERVIEW

SEIG is an ideally suited electricity generating system for the renewable energy conversion due to low cost and size, simple construction, absence of separate dc source for excitation, least maintenance, operational simplicity, brush less construction with cage rotor, easy parallel operation, no hunting and self protection against severe overloads and short circuits due to excitation failure. When an induction generator is directly connected to a grid supply, it draws reactive power from grid. The frequency and voltage of such a generator are fixed and determined by grid. However, for stand-alone operation in remote areas, an external reactive power source such as capacitor is needed to generate voltage and such a generator is called SEIG. The voltage and frequency of a SEIG is not fixed but depends on many factors such as machine parameters, excitation capacitor, speed and nature of loads. That is why the analysis of a SEIG is much more difficult than that of a grid connected generator. A SEIG has poor voltage and frequency regulations and that restricts wide applicability of the generator. A number of techniques have been reported in the literature to improve voltage regulation of SEIG. SEIG suffers from inherent poor voltage regulation due to the difference between the VARs supplied by the shunt capacitors and the VARs required by the load and machine. The frequency of isolated generating unit varies considerably with the change in load and the improved frequency regulation can be achieved using governor control system. The governor control regulates the frequency by adjusting the turbine flow according to the load demand. The operation of a SEIG under unbalanced operating conditions causes additional loss, excessive heating, large insulation and winding stress, and shaft vibrations. Development of a mathematical model for reliability evaluation and performance analysis with an appropriate control strategy for performance improvements of SEIG for MWW based MHPGS has been described in [15].

IV. MEASUREMENT OF POTENTIAL POWER WITH VARIOUS HEAD AND WATER FLOW RATE

The theoretical amount of power available from a micro-hydro power system is directly related to the flow rate (*Q*), head (*H*) and the force of gravity (*g*) as given below,

$$P_{th} = Q \times H \times g \quad (1)$$

To calculate the actual power output (P_{act}) from micro-hydro power plant, it is required to consider friction losses in the penstock pipes and the efficiency of the turbine and generator. Typically overall efficiencies for electrical generating systems can vary from 50 to 70 % with higher overall efficiencies occurring in high head systems. Therefore, to determine a realistic power output as shown in Table IV, the theoretical power must be multiplied by an efficiency factor of 0.5 to 0.7 depending on the capacity and type of system as given below.

$$P_{act} = Q \times H \times g \times e \quad (2)$$

where e = efficiency factor (0.5 to 0.7). The efficiency factor of 0.7 has been used for reliability evaluation of the proposed system based on sewage waste water.

TABLE IV: TYPICAL POWER OUTPUT (W) WITH VARIOUS HEAD (H) IN METERS AND WATER FLOW RATES

H	Flow rate litters per second (lps)						
	5	10	15	20	40	60	80
	Power output (W)						
1	25	49	74	98	196	294	392
2	49	98	147	196	392	588	784
4	98	196	294	392	784	1176	1568
8	196	392	588	784	15688	2352	3136
10	245	490	735	980	1960	2940	3920
15	368	735	1103	1470	2940	4410	5880
20	490	980	1470	1960	3920	5880	7840
30	735	1470	2205	2940	5880	8820	14112
40	980	1960	2940	3920	7840	14112	18816

V. FLOW - DURATION CURVE (FDC) AND ENERGY CALCULATION OF DEVELOPED SYSTEM

In this paper annual as well as daily flow duration curves (FDC) have been obtained by recording municipal waste water (MWW) flows from maximum to minimum from community of the city. Annual Flow Duration Curve (AFDC) and Daily Load Duration Curve (DLDC) of the proposed system has also been obtained for reliability evaluation of the MHP plant as shown in Fig. 1 and 2 respectively. The AFDC and DLDC are used to assess the expected availability of water flow, load variations and power capability to select the type of the turbine and generator. From Fig. 1 it is seen that, there is a difference in waste water flow between summer (March - June) and winter (November - February) and this can affect the power output produced by a MHPS. These variations have been considered in the estimation of total energy generation expected from the site with recycle of the water using solar pumping system. Peak load demand has been considered to evaluate the reliability [11] of the MHPS at different working conditions of the generation capacity, load demand and atmospheres variations. Output power has been estimated at different flow rate and head available in sewage system of the Institute of Technology, Banaras Hindu University; Varanasi, India .

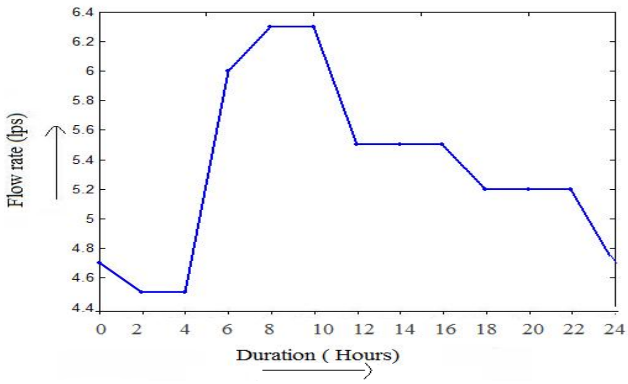

Fig. 1. Daily flow-duration curve (DFDC) of sewage plant

According to AFDC available at sewage power station, the average value of the flow rate capable to produce reliable and stable generation is 5 litters per second (lps). The variation in waste water flow rate from December to March, affects the reliability of the system. During this period waste water head / pressure has been maintained at constant level using backup service by photovoltaic pump [15].

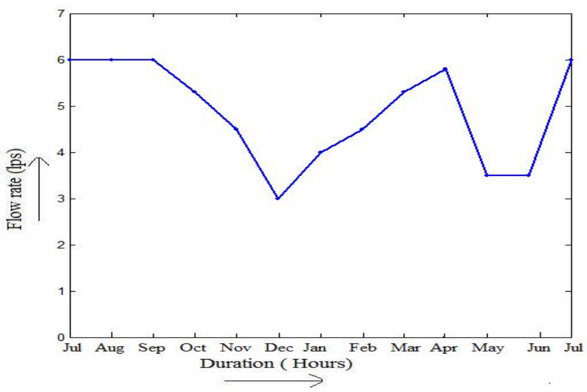

Fig. 2. Annual flow-duration curve (AFDC) of sewage plant

VI. Estimation the Project Cost

A. Estimate for Civil Work

Costs of the civil work are depending on the location, labour charge, rate of the row materials and equipment.

1) *Determination of Quantities:* Determine all goods and components which will be use.

2) *Collection of local/site specific data:*

- Charges and availability of manpower skilled and unskilled labor
- Determine the rate of Raw martial stone, stand etc and cement and equipment
- Approach road.

B. Estimate for Electrical Works

Turbines and generators are main expensive equipment in the project. Turbine is made by joined the two cross laminated wooden plate with iron road; it is much economical compare with others. Cost of Generator is depending on the selection. Basically, SEIG is selected which have many advantage over alternator: one of them less costly and also work on unregulated speed. And costs of other equipments such as transformers switchgear are to be based on recent data.

C. Miscellaneous Provisions

In addition to cost of structure estimate for civil works will also include provision for certain supporting work.

1) *Land:* Land required to be acquired will be determined under different categories viz forest cultivated barren etc, cost of acquisition will then be worked out by considering land rates to be found by local enquiry or in consultation with revenue authorities

2) *Buildings*: This provision will cover the cost of l office buildings and stores and other miscellaneous costs [16].

TABLE V: General Table of Project Cost

Sr. No.	Expenditure	Cost			Not Required
		High×	Medium××	Low×××	
1.	Preliminary expenditure		√		
2.	Land and rehabilitation			√	
3.	Civil works	√			
4.	Buildings	√			
5.	Roads and communication				√
6.	Construction supervision and establishment		√		
7.	Matinees during construction			√	
8.	Plant and equipment	√			
9.	Ecology and environment				√
10.	Miscellaneous works		√		

×High ≥Rs. 10000,
×× Rs.10000>Medium ≥ Rs.5000,
×××Low < Rs.5000

D. Cost economics of a Project Mini Hydro Power Project.

Total cost of project per kW power produced

a) Cost of civil structure

Intake structure and Penstock -- 5,000/-

b) Power House -- 35000/-

Total = Rs. 40000/-
Installed capacity = 2× 5hp = 7.460kW
There for cost per w installed Rs. 5.3/ W

E. Calculation for Load Factor

No of units	No of days	Kwh Generator
	300	53712 kwh

Total units (kwh) considering all the units can run for 300 days.
Total units 300 × 24 × (1 × 7.460) = 53712
Load factor = 53712 × 100 / 65349 = 82.19**%**
Benefit cost Ratio
Knowing that Total capital cost = Rs. 40000 and Number of units generated annually = 53712 units

F. Annual Expenses

Assumptions from other micro hydro power project.
1) Operation cost -- 1% of total cost
2) Maintains cost -- 0.5% of civil work cost
2% of Hydro mechanical electrical cost
3) Annual depreciation charges – 2% total cost
4) Interest rate -- 10% from bank
5) Selling price Rs. 300 per unit
6) Life of project 50 Year after commencement
7) Duration of project 1 year completion
1) Operation cost = 0. 2×40000 = Rs.8000
2) Malignance cost
a) 1% of civil structure cost 0 .1 × 5,000= 500
b) Depreciation charges = 0.02 × 40000 = 800
c) Interest charges = 40000 × 10 × 1 / 100
= 4000
d) Miscellaneous Incidental charges = 0.02 × 40000
= 800
Therefore total annual expense Rs. 14,100

Consider 10% losses in the transmission and other losses of energy
Annual revenue = Total units × selling price per unit
= 48341× 3 = 145023
Benefit cost Ratio = annual revenue / annual expenses
= 145023 / 14100 = 10.2
Breakeven point Total capital cost = 40000
Capital expenditure in 1year = 40000

a. Year From the commencement of project
b. Year after commence con of project
c. Sum or Expenditure at beginning of year in Rs.
d. Sum or Expenditure at during year in Rs.
e. Interest 10% of column c in Rs.
f. Operation cost and Depreciation Expenses in Rs.
g. Annual Power Generation in kw
h. Cross Revenue @ Rs. 3. 00 per unit in Rs.
i. Net Revenue Column h – Column f in Rs.
j. Annual surplus column i – column e in Rs.
k. Sum of change at the end of year in Rs

TABLE VI: ESTIMATION CHART [16]

a.	1	2	3
b.	-	1	2
c.	-	40000	11400
d.	40000	10100	10100
e.	-	4000	1140
f.	-	8800	8800
g.	-	53712	53712
h.	-	145023	145023
i.	-	136223	136223
j.	-	13223	135083
k.	40000	82123	113583

VII. CONCLUSION

MWW based MHPS is highly stable, cheap and capable of producing reliable power at need because the head/pressure of the sewage reservoir has been maintained at constant using back up service by PV pump during summer and winter cycles [11], [15]. On the basis of the proposed concept and developed experimental system: MHPGS at Banaras Hindu University, Varanasi, Uttar Pradesh, (India), a number of experimental test were performed for designing of an AFDC / DFDC for energy estimations. Generating Capacity of MHPS based on MWW at different head available in sewage system of the University has been evaluated successfully. Turbine – generator sets has been recommended for different heads of the MWW for reliable operation of the MHPS. SEIG has been used in the developed MHPS for reliable power generation. MWW flow rate and head have been measured considering summer / winter and day / night cycles and typical power output has been estimated at different flow rate and head at sewage plant. In the point of the view of the prevention of the holy Ganga River from water pollutions, MWW has recommended for supply to local farmers for irrigation purpose after proper chemical treatment of the water and generation of the electrical energy. Future research work is proposed for Micro / Pico / Nano hydro power generation from overhead tanks of the bathrooms and kitchen to charge the mobiles and small chargeable batteries.

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