ICSE
2009

PROCEEDINGS OF THE FIRST INTERNATIONAL CONFERENCE ON SCIENCE AND ENGINEERING

Volume - 1

Electronics
Electrical Power
Information Technology
Engineering Physics

Sedona Hotel, Yangon, Myanmar
December 4-5, 2009

PROCEEDINGS OF THE
FIRST INTERNATIONAL CONFERENCE
ON
SCIENCE AND ENGINEERING

Volume - 1

Electronics
Electrical Power
Information Technology
Engineering Physics

Organized by
Ministry of Science and Technology

DECEMBER 4-5, 2009
SEDONA HOTEL, YANGON, MYANMAR

ELECTRICAL POWER ENGINEERING

Pico-Hydropower System for Rural Electrification

Aung Ze Ya
Electrical Power Engineering Department, Yangon Technological University
Ministry of Science and Technology, Myanmar
dr.aungzeya010@gmail.com

Abstract **— Hydropower is an eco-friendly clean power generation method. Myanmar has enormous hydropower resources about 108,000 MW. This study discusses the hydropower technologies based on the considerations of hydraulic turbine and hydroelectric generator for pico-hydropower range (low-head) development. Fixed-blade axial-flow propeller turbine and single-phase salient-pole synchronous generator are selected according to their characteristics in this paper. These machines are directly coupled to eliminate the speed increaser loss. Compact, reliable and cost-effective design of 2kW Pico Hydropower system is tested with both resistive and inductive loads.**

Keywords**—Hydropower, Fixed-blade axial flow propeller turbine, salient-pole synchronous generator, directly coupled, Pico.**

I. Introduction

The move towards a de-carbonized world, driven partly by climate science and partly by the business opportunities it offers, will need the promotion of environmentally friendly alternatives, if an acceptable stabilization level of atmospheric carbon dioxide is to be achieved.

This requires the harnessing of natural resources that produce no air pollution or greenhouse gases and provides comfortable coexistence of human, livestock, and plants.

Under the 1997 Montreal Protocol, governments agreed to phase out chemicals used as refrigerants that have the potential to destroy stratospheric ozone [7].

Therefore, hydroelectric energy which is one of the renewable energy plays an essential role in energy sector.

The hydrologic cycle is important to hydroelectric plants because they depend on water flow. This cycle can be briefly explained as the following process:

(1) The sun heats the ocean.
(2) Ocean water evaporates and rises into the air.
(3) The water vapor cools and condenses to become droplets, which forms clouds.
(4) If enough water condenses, the drops become heavy enough to fall to the ground as rain and snow.
(5) Some rain collects in ground-wells. The rest flows through rivers back to the ocean.

Step-by-step energy-conversion stages are included in hydroelectric power system. Hydro energy exists in the water resources such as waterfalls, creeks, rivers and streams. From these resources, potential energy and kinetic energy are firstly achieved. Secondly, hydraulic turbine converts these energies into mechanical energy. Hydroelectric generator converts the developed mechanical (output) energy from hydraulic turbine into electrical energy. Therefore, the hydraulic turbine and hydroelectric generator are the brain and heart of the hydropower system. Finally, the generated electrical energy is transmitted and utilized for consumers. The amount of available energy depends on the amount of water flow rate, the gross head and the force of gravity. Power potential in a particular site can be calculated using the following equation:

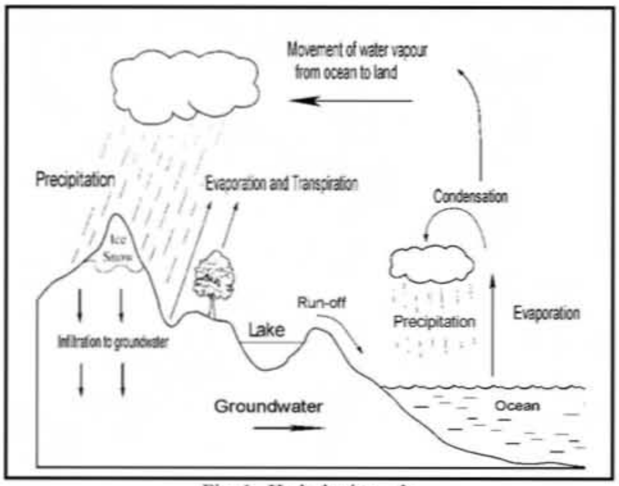

Fig. 1 Hydrologic cycle

$$P = Q \times H \times g \times \eta \qquad (1)$$

where, P = power output (kW)
Q = usable flow rate (m^3/s)
H = gross head (m)
g = gravitational constant (9.8 m/s^2)
η = efficiency factor (0.5 to 0.7)

Depending on the storage of water, hydroelectric plants can be classified as: (1) Run-off-river plant with storage pondage; (2) Run-off-river plant without storage pondage; and (3) Reservoir plant. Based on the type of load, these plants are divided as: (1) Base load plants; (2) Peak load plants; and (3) Pumped-storage plants [1].

Moreover, hydroelectric plants are distinguished according to the installed capacity as :(1) Pico-hydropower (up to 5 kW); (2) Micro-hydropower (up to 100 kW); (3) Mini-hydropower (up to 1 MW); (4) Small-hydropower (up to 5 MW) and; (5) Conventional-hydropower (above 5 MW) [2]. Among the above schemes, pico-hydropower and micro-hydropower are very popular for rural electrification. But, Pico-hydropower system is only considered in this paper.

Rural electrification involves investment in creation of basic power infrastructure in rural areas. And it can be used the same to trigger off socio-economic development. According to the following reasons, rural electrification recognized as key to rural development. These reasons are: (1)

agricultural productivity; (2) rural industrializations; (3) rural communication; (4) rural employment; (5) increase in income level of rural population; (6) improvement in quality of life; and (7) universal availability of electricity at affordable price; and (8) universal goal [2].

Two types of rural electrification are: (1) stand-alone (isolated-owned) power station and (2) community-owned power station. But, some problems are detected with the stand-alone power station. These problems are: (1) high cost of construction, (2) low revenue, (3) high salary component (4) not integrated with local development and (5) poor maintenance. On the other side, the advantages of the community-owned power station in rural and hilly regions are briefly mentioned as: (1) economical; (2) availability of large amount of power for livelihoods; (3) local involvement in building and maintenance; (4) possibility of complete localization; and (5) building effective communities [2].

II. Hydraulic Turbines

Turbines can be crudely classified as high-head, medium-head, and low-head machines, as shown in Table I. Electricity generation usually requires a shaft speed to minimize the speed change between the turbine and the generator. Since the speed of any given type of turbine declines with head, low-head sites need turbines that are inherently faster under a given operating condition. Turbines are also divided by their principle of operation and can be either impulse or reaction turbines. The rotor of the reaction turbine is fully immersed in water and is enclosed in a pressure (spiral) casing. The runner blades are profiled so that pressure differences across them impose lift forces, just as on aircraft wings, which cause the runner to rotate. In contrast, an impulse turbine runner operates in air, driven by a jet (or jets) of water. There are 3 main types of impulse turbine in use: the Pelton, the Turgo, and the Crossflow turbines. The two main types of reaction turbine are the propeller (with Kaplan variant) and Francis turbines. The approximate ranges of head, flow and power applicable to the different turbine types are summarized in the chart of Figure 4 (up to 500kW power). These are approximate and depend on the precise design of each manufacturer [5]. Two different groups of turbines are shown in Fig. 2 and 3.

(a) Single-jet Pelton(b) Multi-jet Pelton (c) Turgo (d) Crossflow
Fig. 2 Group of impulse turbine

(a) Propeller (b) Kaplan (c) Francis
Fig. 3 Group of reaction turbine

TABLE I
TURBINE TYPES BASED ON HEADS

Turbine Runner	High-Head (>50m)	Medium-Head (10-50m)	Low-Head (<10m)
Impulse	Pelton Turgo Multi-jet Pelton	Crossflow Turgo Multi-jet Pelton	Crossflow
Reaction		Francis PAT	Propeller Kaplan

Typical efficiency ranges of turbines are given in Table II. Turbines are chosen or are sometimes tailor-made according to site conditions. Selecting the right turbine is one of the most important parts of designing a hydroelectric system, and the skills of an engineer are needed in order to choose the effective turbine for a site, taking into consideration cost, variations in head, flow, and the amount of sediment in the water and overall reliability of the turbine [6].

In this paper, the low head pico-hydropower system is emphasized. Therefore, the reaction type, propeller turbine is chosen according to Table I, II and Fig. 4. This choice is also intended to get cost-effective design, easily fabrication and simple implementation in rural areas.

TABLE II
EFFICIENCY RANGE OF TURBINES

Turbine Type	Efficiency Range
Impulse turbines: Pelton Turgo Crossflow	 80-90% 80-95% 65-85%
Reaction turbines: Francis PAT Propeller Kaplan	 80-90% 60-90% 80-95% 80-90%

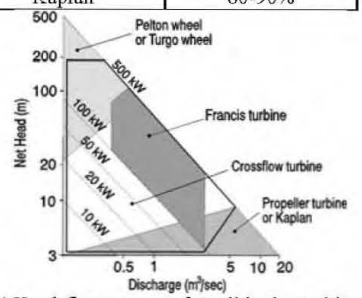

Fig. 4 Head-flow ranges of small hydro turbines

III. HYDROELECTRIC GENERATORS

Electrical power can be generated in either AC or DC. AC has the advantage of allowing the use of common household appliances and tools and is much more economical for transmitting power to consumers. Thus, AC system is considered in this study. Generators operation is quite simple: when a coil of wire is moved past a magnetic field, a voltage is induced in the wire. Alternating current (AC) generators also referred to as alternators. They generate varying voltages, which alternate above and below the zero voltage point. It is this process that produce AC electricity. They are two type of generators; synchronous and asynchronous.

Synchronous generators are standard in electrical power generation and are used in most power plants. Asynchronous generators are more commonly known as induction generators. Both of these generators are available in three-phase or single-phase systems. And, both machines may have the same stator design but different rotor design as illustrated in Fig.5.System capacity, type of load and length of the transmission/distribution net-work dictate whether a single- or three-phase generator should be used [6]. Selection of the generators based on size of scheme is shown in Table III. Other considerations for selection of generators are: (1) maximum turbine power; (2) run away speed of turbine; (3) horizontal or vertical construction; (4) isolated or parallel operation; (5) constant load or variable load; (6) availability of grid supply and; (7) reactive power supply.

TABLE III
SELECTION OF GENERATOR

Size of Scheme	Up to 10 kW	10 to 25 kW	More than 25 kW
Type of Generator and Phase	Induction or Synchronous, Single or three-phase	Induction or Synchronous, Three-phase	Synchronous, Three-phase

(a) (b)

Fig. 5Different Rotor Design:
(a) Salient-pole rotor
(b) Cylindrical-pole rotors

Full-load efficiencies of synchronous generators vary from 75 to 90 percent, depending on the size of the generator. Larger generators are more efficient, and three-phase generators are generally more efficient than single-phase ones. The efficiency will be reduced by a few percentage points when being used at part load (e.g., at 50 percent of the load). Efficiency of induction generators is approximately 75 percent at full load and decreases to as low as 65 percent at part load. There are other factors to consider when selecting a generator for your system, such as capacity of the system, types of loads, availability of spare parts, voltage regulation and cost. If high portions of the loads are likely to be inductive loads, such as motor and fluorescent lights, a synchronous generator will be better than an induction generator. Induction generators in stand-alone application mode cannot supply the high-surge power required by motor loads during start-up [6].

By using synchronous generator, there is no affection against grid when parallel running. On the other hand, big over current will rush and voltage drop of grid will occur if induction generator is applied [2]. Therefore, salient-pole synchronous generator is selected in this study. The run away speed of the propeller turbine is 1000 r.p.m. So, the number of poles of generator must be 6 in order to match with turbine speed and standard frequency of 50Hz. And, the same shaft is used for both turbine and generator.

IV. PICO-HYDROPOWER SYSTEM

A. Specifications

The main specifications of Pico hydropower system can be listed as shown in the following Table IV.

TABLE IV
SPECIFICATIONS

Turbine type	Fixed-blade axial flow propeller
No. of turbine blade	4
Head	3 m
Flow rate	0.08 m^3/s
Generator drive system	Direct-coupled
Generator type	Salient pole synchronous
Generator capacity	2 kVA
Supply system	Single-phase A.C
Rated speed	1000 r.p.m
No. of poles of generator	6
Power factor	0.8
Frequency	50 Hz
Voltage	220 V

B. Consideration of Loads and Power Factors

The selected loads for testing are 500 W halogen lamp, 1000W halogen lamp, 40Wfluorescent lamps and (1-phase) 0.75hp induction motor. Total number of 40W fluorescent lamps is 10. Therefore, total real power for these lamps is 400W. The different loads are arranged in different cases as mentioned in the Table V.

TABLE V
LOADS

Loads	Total Real Power
1000W Halogen lamp	1000W
1000W Halogen lamp +(10x40W fluorescent lamp)	1400W
1000W Halogen lamp +0.75 hp (559.5W) induction motor	1559.5W
500W Halogen lamp+1000 W Halogen lamp +(10x40 W fluorescent lamp)	1900W

Since poor power factors give rise to relatively high currents for the useful power delivered, these are to be avoided in the electrical system design as far as possible. In general the generator is sized on the basis of a conservative estimate of overall power factor and care is taken to protect the generator windings from over current which may be caused by unexpected poor power factor. Capacitive and inductive effects counteract each other. It is possible to improve the power factor of a predominantly inductive current by adding capacitors to the circuit. The only penalty here is the cost of the capacitors, but sometimes this can be less than the cost of increasing the supply current [4]. In this paper, the loads are considered by using basic electrical theory as determined in the following four cases.

1) *Case1:* 1000W halogen lamp is only included. Therefore, the power factor is one.

2) *Case 2:* 40Wfluorescent lamp is inductive load which has the lagging power factor. That lagging power factor can be taken as 0.7[4].So, the power factor of this case is calculated in the following:
   Total real power, P = 1400W
   Reactive power of 40 W fluorescent lamps
   $=\sqrt{[(400/0.7)^2 - 400^2]} = 408.0816\text{VAR}$

   Total reactive power, Q =
   $\sqrt{1400^2 + 408.0816^2} = 1458.2629\text{VAR}$
   Power factor = (P/Q) = 0.96 (lagging)

3) *Case 3:* The power factor for 0.75hp induction motor is 0.7 (lagging). Then, the power factor of entire case is evaluated as the following:
   Total real power, P = 1559.5W
   Reactive power of 0.75 hp motor
   $=\sqrt{[(559.5/0.7)^2 - 559.5^2]} = 570.8042\text{VAR}$

   Total reactive power, Q =
   $\sqrt{1559.5^2 + 570.8042^2} = 1660.6799\text{VAR}$
   Power factor = (P/Q) = 0.94 (lagging)

4) *Case 4:* Total resistive load is 1500W. The power factor for 0.75hp induction motor is 0.7 (lagging). The power factor for this case is predicted as :
   Total real power, P = 1900W
   Reactive power of 40 W fluorescent lamps
   $=\sqrt{[(400/0.7)^2 - 400^2]} = 408.0816\text{VAR}$

   Total reactive power, Q =
   $\sqrt{1900^2 + 408.0816^2} = 1943.3298\text{VAR}$
   Power factor = (P/Q) = 0.97 (lagging)

C. Testing and Results

(a) (b) (c)

Fig. 6 Photos of Pico-Hydropower System
(a) salient-poles Synchronous Generator
(b) turbine-generator set is put into spiral casing
(c) 40 W fluorescent lamps before operating

Fig. 7 Testing with 1400 W Load

Fig. 8 Testing of Pico-Hydropower System

Testing of Pico-Hydropower System can be obviously seen in the above figures. Fig .7 shows the 40W fluorescent lamps and 1000W halogen lamps are supplied by generated pico-hydropower. The results are described in the Table VI.

TABLE VI
RESULTS

Case	Load(W)	Voltage(V)	Current(A)
1	1000	220	4.5
2	1400	207	7
3	1559.5	203	8
4	1900	183	11

V. Conclusion

There are some problems of supplying power to rural and hilly regions by national grid system such as: (1) very long distance to transmit; (2) difficult to maintain; (3) uneconomical due to poor load. Community-owned hydropower plant is the most suitable power source for communities living in these regions. Fixed-blade axial-flow propeller turbine is chosen because that turbine is one of the most cost-effective turbine options for low head scheme. Moreover, its efficiency is high and it can be easily constructed. Single-phase, 2 kVA salient-pole synchronous generator is selected in order to supply the inductive loads and to get the good performance. Direct coupled drive system is used to eliminate the loss of speed increaser. Poor power factor can give the undesirable effects to the system. Therefore, the suitable method to improve the power factor or balancing the loads to get the good power factor should be considered. Installations of pico-hydropower system at three possible locations are illustrated in Fig. 9, 10 and 11[2]. Although hydropower plant consists of many components, the turbine and generator are only studied for pico-hydropower system in this paper.

ACKNOWLEDGEMENT

The author would like to express his deep gratitude to H.E, U Thaung, Minister, the Ministry of Science and Technology, for the celebration of this conference at Yangon, Myanmar. The author also offers his appreciation to his parents for their supports, encouragement and valuable guidance.

REFERENCES

[1] Maung Aung Ze Ya, " Design and Construction of Micro-Hydropower Plant," M.E.thesis, Mandalay Technological university, Mandalay, Myanmar, Feb, 2002.

[2] Maung Aung Ze Ya, " Design and Construction of Mini-Hydropower Plant," Ph.D..thesis, Yangon Technological university, Yangon, Myanmar, Dec, 2004.

[3] Alternate Hydro Energy Centre, *International Course on Technology Selection for Small Hydropower Development,* IIT, Roorkee, India: Alternate Hydro Energy Centre, 2003.

[4] A. Harvey et al., *Micro-Hydro Design Manual*, London, England: IT Publications Ltd, 1993.

[5] British Hydropower Association, *A Guide to UK Mini-Hydro Developments*, London, England: BHA, 2005.

[6] Natural Resources Canada, *Micro-Hydropower Systems,* Canada: Natural Resources Canada, 2004.

[7] Abdeen Mustafa Omer, "Energy consumption, development and sustainability in Sudan", *Sudan Engineering Society Journal,* vol.52, pp.35-43, September, 2006.

[8] A.T. Sayers, *Hydraulic and Compressible Flow Turbomachines,* McGraw-Hill International Editions, Singapore: McGraw-Hill Book Company, 1992.

[9] Luo Gaorong, *Small Hydro Power in China- Experience and Technology,* Hangzhou, China: Hangzhou Regional Centre, 1996.

[10] R. L. Daughherty, *Hydraulic Turbines*, 3rd ed., New York, USA: McGraw-Hill Book Company, 1920.

[11] P. K. Nag, Power Plant Engineering, 2nd ed., New Delhi, India: Tata McGraw-Hill Publishing Company Limited, 2006.

Fig. 9 Installation of pico-hydropower system at waterfall

Fig. 10 Installation of pico-hydropower system at small dam

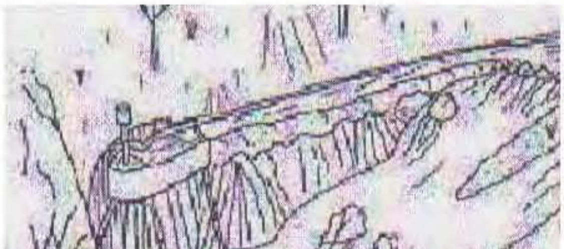

Fig. 11 Installation of pico-hydropower system at site channel