ABSTRACT

Electricity is an important ingredient for socio-economic development of a society. In households electricity has an impact on living standard, health, education to mention but a few. However, access to it in rural areas has been difficult in many African countries due to different reasons, cost being one of them.

This paper proposes a low-cost small hydropower plant that can benefit communities in rural areas which are endowed with small hydropower resources. The plant employs a synchronous–induction generator combination in a power generation scheme.

1. INTRODUCTION

Electricity is one of the important ingredients for industrial and socio-economic development of a country or region [1]. There is evidence in most parts of the world, that areas without electricity are far less developed than those with electricity [2]. In households electricity has an impact on living standards, health education etc. In terms of access to electricity, rural communities are the most affected due to several reasons, which include priorities where there is insufficient supply and being economically not viable when electric supply is to be implemented in a traditional way of extending the existing grid [3]. The scenario can be changed if attention is given to a possibility of electrifying rural areas utilizing locally available energy sources for electricity generation, of which small hydropower plant (SHP) being one of them.

Utilization of small hydropower in rural areas is not a new phenomenon; it started with wooden waterwheels many years ago in parts of Europe and Asia, where it was used for milling grain. Improved engineering skills during industrial revolution and need for high speed devices for electricity generation led to the development of modern-day turbines. Exploitation of large scale hydropower for electricity generation and dominance of oil in energy provision have made SHPs uncompetitive and consequently partially abandoned. However, rising cost of fossil fuels and environmental concerns make SHPs to become an attractive energy production alternative [4].

Small hydro power plants if implemented in a cost effective manner can be the answer to electrification of rural areas which are around technical and economic viable hydro potentials. The small hydro power plants referred to in this paper have capacity not exceeding 10MW [5]. In this group, plants of 100kW or less are categorized as micro and others up to 1MW are termed as mini hydro power plants [6].

It is cost effective to have a minimum number of generating units in a given installation; nevertheless, multiple units may be necessary to make most efficient use of water where flow variation is great.

In this paper, an innovative two unit small hydro power plant of run of river type is presented. The plant is intended to cater for rural communities located far away from grid. The proposed plant employs the outcome of research and development in the fields of machines and power electronics.

The paper has five sections. Introduction gives an overview of SHP and the role they can play in rural electrification. Section two describes energy conversion elements in SHP while section three covers current and the proposed SHP. In section four a comparison with other alternative plants is highlighted and finally in section five are conclusions.

2. ENERGY CONVERSION ELEMENTS

Hydro energy is based on water cycle and its drop from higher level to a lower land surface. Conversion of the energy to electricity takes place in electro-mechanical generating units each made of a governed hydraulic turbine coupled to a generator.

2.1 TURBINES AND GOVERNORS

In hydropower plants, hydraulic turbines are prime movers driving the respective coupled generators. They convert fluid power into mechanical power through the rate of change of angular momentum of the fluid. The action of the turbine runner is to remove this angular momentum or to straighten out the fluid streamlines. The effect of this change in angular momentum is to induce torque on the shaft of the runner coupled to the generator. The speed of rotation is the rate at which this angular momentum is changed and also determines the frequency of power generated.

The power output of hydro system is estimated as

$$P_m = \eta \rho g q h$$

Whereby \(\eta\) is the hydraulic efficiency of the turbine; \(\rho\) is water density \([\text{kg/m}^3]\); \(g\) is the gravitational acceleration \([\text{m/s}^2]\); \(q\) is plant discharge \([\text{m}^3/\text{s}]\) and \(h\) is the net effective head \([\text{m}]\).

In order to keep the frequency of the generated power within the allowed deviation from the specified frequency of 50Hz or 60Hz, each hydraulic turbine is equipped with
a governor. The governor measures the rotational speed of the generator and compares it to the reference value and then based on the error signal, instructs the actuator to open or close wicket gates or nozzles which control water flow into the turbine.

Conventional governors are designed to operate as proportional control systems characterized by a widespread droop of 4% to 6%. Set point frequency of these governors can be adjusted. Adjustment of set point allows power system operators to decide on how the demand is shared by the generators in the system.

2.2 GENERATORS

Generators convert the mechanical power supplied by prime-movers into electrical power through electromagnetic torque mechanism resulting from the tendency of magnetic flux caused by armature current and field current to align themselves. Generators used in hydropower plants are generally 3-phase synchronous machines with stationary armature and salient-pole rotating field structure. Induction generators are not common but are increasingly being used in micro-hydro schemes.

2.2.1 Synchronous generator

A single synchronous generator supplying power to an impedance load acts as a voltage source whose frequency is determined by its prime-mover speed. The current and power factor is then determined by the generator field excitation and the impedance of the generator and that of the load.

When two or more synchronous generators operate in parallel, as is normally the case, dynamic characteristics of the power system are dominated by aspects of electromechanical energy interchange of the synchronous generators in the system. Requirement of reliable power supply is; all synchronous generators in the system should maintain synchronous operation.

Synchronous generators are rated in terms of maximum kVA load which they can carry at a specific power factor without overheating. The active power of a synchronous generator is limited by the capability of its prime-mover. When the active power loading and voltage are fixed, the allowable reactive power loading is limited by either armature or field heating.

2.2.2 Induction generator

Induction machines commonly used as induction generators have cage rotors. Their attractive features are simplicity and ruggedness in construction and consequently low maintenance cost. However, they have three main setbacks: terminal voltage regulation and generation frequency control pose great challenge and also can not generate reactive power instead they absorb it for their operation.

As a generator, an induction machine connected to an AC supply system and driven by a prime-mover at a rotor speed above the synchronous speed, relative direction of rotation between rotor bars and flux is reversed hence slips is said to be negative. In this situation the rotor voltage and current are correspondingly reversed, as a result rotor shaft power supplied by the prime-mover is transferred across air-gap to the stator. Part of the transferred power is delivered to the system to which the machine is connected as a generator. The net power output of the machine which is a function of the slip is mechanical power in the shaft less the losses within the machine. With terminal voltage maintained constant, power transferred across the air-gap is proportional to the slip.

2.2.3 Synchronous - induction generator attributes

The power plant in consideration in this paper has a capacity less than 2MW. Major attributes of synchronous and induction generators of capacities not exceeding 1MW are briefly summarized in the table 1 below.

<table>
<thead>
<tr>
<th>Synchronous generator</th>
<th>Induction generator</th>
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<tbody>
<tr>
<td>Efficient.</td>
<td>Moderately efficient.</td>
</tr>
<tr>
<td>Expensive.</td>
<td>Less expensive.</td>
</tr>
<tr>
<td>Requires maintenance.</td>
<td>Rugged and robust, little maintenance.</td>
</tr>
<tr>
<td>Reactive power flow can be controlled through excitation.</td>
<td>Sink of reactive power.</td>
</tr>
<tr>
<td>Fixed speed hence very stiff.</td>
<td>Small change in speed with torque, hence more compliant.</td>
</tr>
<tr>
<td>Respond in an oscillatory manner to sudden changes in torque.</td>
<td>Respond to sudden inputs in no oscillatory way.</td>
</tr>
<tr>
<td>Suitable for connection to weak networks. Used in autonomous systems.</td>
<td>Suitable for weak networks only with power electronics.</td>
</tr>
<tr>
<td>Requires special synchronization equipment to connect to mains/other generator for parallel operation.</td>
<td>Can be simply synchronized to the mains.</td>
</tr>
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</table>

3. IMPLEMENTATION OF SHP

Like other hydropower schemes, SHP schemes are classified according to head, mode of head concentration and flow regulation. According to head, the schemes are identified as low, medium or high head schemes. Depending on the mode of head concentration, they are as well grouped as dam, diversion or mixed schemes. Flow regulation makes SHP schemes to be classified as run of river, daily regulation or seasonal regulation schemes.
3.1 FEATURE OF EXISTING SHPs

The existing small hydropower plants are mainly run of river type; their generation capacity varies with weather conditions.

Water is extracted from a river using weir and canals that direct it to forebay where it is distributed to penstocks. Each penstock conveys the water under pressure to a turbine coupled to a generator to form a generating unit. As mentioned earlier, except for some micro schemes which employ induction generators, synchronous generators are used for electricity generation.

3.2 PROPOSED SHP AND OPERATION

Small hydropower plant proposed in this paper makes use of the merits of both synchronous and induction generators in order to reduce investment and maintenance cost of the plant. If implemented, the plant is expected to be of low cost hence economic viable power source for rural electrification.

The plant consists of two generating units, one with synchronous and the other employing induction generator in parallel as shown in Figure 1. Both turbines are governed by systems incorporating electric servo-motors in place of conventional governors whose cost and sophistication affects competitiveness of SHP. Static Var Compensator (SVC) is introduced to the generator bus to supplement generation of the required reactive power for the inductor generator.

Voltage regulation is taken care of by the automatic voltage regulator (AVR) included in synchronous generator excitation control system and the SVC.

Operation of the plant starts with running the synchronous generator unit until steady state voltage and frequency are established thereafter plant loading is initiated. When certain loading level of the synchronous generator is reached, the induction generator unit is brought into the system. By then, SVC will be supplementing reactive power generation of the synchronous generator which also determines generator bus voltage and frequency. Induction generator on the other side will follow the synchronous generator which gets rid of the necessity of synchronizing equipment. Any change of load to the plant will cause change in power output of the synchronous generator. However, at certain preset load to the plant, power relay will instruct the corresponding stepwise adjustment of opening of the gate/valve to the turbine driving induction generator thus adjusting its power output and sharing of the load between the two generators.

Reliability of supply from the proposed plant depends on the synchronous generator since self excitation operation regime for the induction generator is excluded.

Capacity of SVC will depend on size of the induction generator and maximum reactive power to be supplied from the plant so as to maintain voltage at the generation bus within allowable statutory limits.

4. ADVANTAGES OF THE PROPOSED SHP

The proposed SHP strategically employs combination of synchronous and induction generators in conversion of mechanical power supplied by turbines into electrical power. Performance efficiency of each of these machines can be estimated. Efficiency of large induction generators is comparable to that of synchronous generators [7]. For example, for both induction and synchronous machines of 3000-kW, operating as generators will have an efficiency of about 96.3% [9].

In a case where an isolated SHP is having only induction generators and supply power to an AC load, the
generators will be operating as Self Excited Induction Generators (SEIGs). Since AC loads operate at a specific frequency, generators will have to operate at either Variable Speed Constant Frequency generation (VSCF) or Constant Speed Constant Frequency generation (CSCF) mode otherwise frequency converters should be included. In VSCF operation, efficiency of SEIG falls with increasing speed [8]. On the other case, CSCF operation leads to loading the plant with constant load thus requires electronic load frequency controllers which employ dump loads.

In this regard, authors’ opinion is that neither a plant with only synchronous generators nor induction generators is better than the proposed SHP.

5. CONCLUSION

The paper has highlighted a possibility of low-cost small hydropower plant that can supply power to communities which have small hydro potentials. The plant exploits merits of synchronous and induction generators and make use of recent achievements in power electronics for reactive power generation by means of SVC. Introduction of electric servo-motors in load frequency control systems cut down further investment cost of the proposed SHP. Implementation of the proposed plant together with low cost distribution systems, will effectively contribute to rural electrification.

6. REFERENCES


6.2 BIBLIOGRAPHY


Principal author
Abrahaman Kilimo holds an Msc. degree in Electrical engineering from Dzhdanov Metallurgical Institute in Ukraine. He is an assistant lecturer at Dar es Salaam Institute of Technology in Tanzania. Currently he is a DTech student at CPUT, researching on techniques of employing SHPs in distributed generation.

Co-author
M.T.E. Kahn holds a DTech. degree in Engineering from CPUT. He is presently a professor in Power Electronics at the same University heading the Center of Distributed Power and Electronic systems.

Abrahaman S.G. Kilimo & Prof. M.T.E. Kahn
Cape Peninsula University of Technology
Electrical Engineering Department
Centre for Distributed Power & Electronic Systems
P.O. Box 1906, Bellville7535
Cape Town, South Africa
E-mails, asgkilimo@yahoo.com & khant@cput.ac.za

Presenter: The paper is presented by Abrahaman Kilimo.