Educational Renewable Energy Screw Wheel Technologies for Pico Hydropower Generation and Sustainability

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Abstract.

Various laboratory-scale inclined axis Screw Wheel Technological Systems simulating pico hydroelectric generation and sustainability have been constructed in ASPETE, under the supervision of the Austrian B.O.K.U. University and used in the educational curriculum of Renewable Energy and Sustainability Programme at the M.Sc. in "Management Technologies of Waters, Soft Energy Systems and Environmental Mechanics (M.T.W.-S.E.S.E.M.)". The mainlines of the small screw turbine systems construction, simulating pico hydropower generation and the measurement procedures are described. The small hydraulic screw turbine is simple to make and use inexpensive components, most of which can be found in standard science laboratories. From the "M.T.W. - S.E.S.E.M." M.Sc. courses experimental results, the small-scale screw turbine was found to have good hydrodynamic performances for small water flow rates. The educational renewable energy screw wheel technological system simulating pico hydroelectric generation demonstrates the principles of hydropower and sustainability and is well suited for education in hydraulic renewable energy and sustainability.

Keywords: Renewable Energy Technologies, Small Hydropower, Screw Turbine, Environmental and Renewable Energy Education, Sustainability

1. Introduction

Small, Micro and Pico hydropower is an eco-friendly, fish friendly, non-polluting renewable source of energy. Hydropower represents a reliable source of renewable energy with majority of global renewable energy production contributing over 16% of the global electricity generation and accounting for 76% of the total renewable electricity supply. However, only a third of the total world hydropower capacity has been developed and most of this growth and development is concentrated in developed countries especially in Europe (W.E.C., 2015). Large scale hydropower potential being mostly developed, the focus is now shifted to small scale hydropower (ESHA, 1998). Within the small scale hydropower sector, very low head sites below 5 m, formerly disregarded considered uneconomical for developing hydropower, are recently getting renewed interest with governments providing subsidies to meet the renewable energy targets (Pelikan & Lashofer, 2012). In order to develop these under utilised energy resources, conventional highly efficient low head hydraulic turbine technologies such as Kaplan turbines are not economically viable because of the large size of the turbine required for very low head installations, requirement of special flow control mechanism and the risk they impose on the environment (Stergiopoulos *et al.*, 2010). Technological development is therefore required to harness this very low head energy potential. Efforts have been made to develop Archimedean Screw Water Wheels technologies that suitably harness the very low head energy source (Stergiopoulou *et al.*, 2012). The profound roots of the Archimedean hydraulic ideas and screw technology had been lost in the forgotten legacy of the history and the mythology. During the last years, the inverse use of the classical Archimedean screw, as a kind of inverse screw pump-turbine, is under discussion within the hydropower scientific community (Kantert, 2008). The screw renaissance taking place actually throughout the world in the promotion and construction of renewable energy valorises Archimedean Screw Turbines for low, ultra-low and zero-head small hydro plants. Some cochlear inclined axis small hydro plants were installed during the last decade in Central Europe by various industrial companies, which were based on the inversion of the energy flow in their pumps operation and turning the old screw pumps into new screw turbines (Pelikan & Lashofer, 2012). Low, ultra-low and zero-head cochlear hydropower plants are developing very slowly, due to the fact that recent Archimedean screws are a new type of turbines in all countries throughout the world. For sites with relative greater heads, and relative greater water flows, the cascades of two or more similar energy spiral rotors in series and in parallel could give efficient Archimedean hydropower solutions. In Greece, small hydroelectric development has not reached the saturation point. However, if the number of sites for large hydro projects is relatively limited in some Greek Water Districts, this is not the case for small hydro resources, especially for the Archimedean small hydropower plants based on small rivers and streams. In such cases of low-head H(m) sites the time flow series Q(t) and the Flow Duration Curve are the base for the efficient hydropower design (Figure 1).

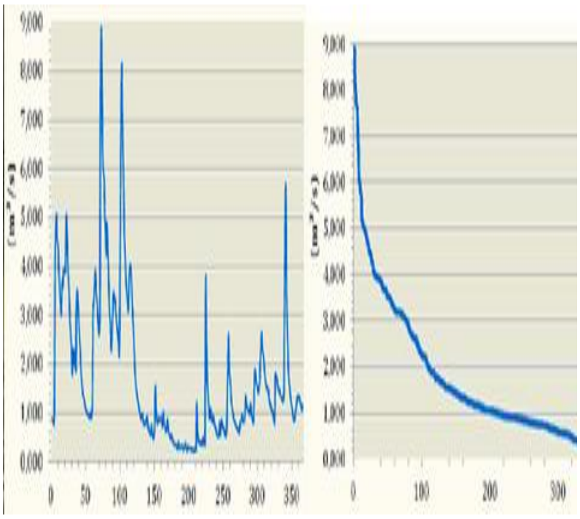

Figure 1. A typical low head watercourse with its time flow variation and the Flow Duration Curve

The new Archimedean small hydropower philosophy should attract an increasing amount of interest in Greece due to their advantages, and mainly to the fact that such Archimedean small hydro plants are relatively easy to develop, and they can make an important contribution to the energy supply in remote and rural areas, they can play an important role in the regional and national energy scenarios and satisfy different other requirements following a multipurpose philosophy. Figure 2 gives photorealistic artistic views in "virtual sites" of one inclined Archimedean Screw Small Hydropower Turbine, and three screw turbines in series and parallel (Stergiopoulou *et al*., 2013).

Figure 2. Photorealistic artistic views for one Archimedean Screw, three screw in series and three screws in parallel, made by A. Stergiopoulou

2. Towards Educational Screw Wheel for Pico Hydropower in ASPETE

ASPETE is a higher education institution offering through the Civil Engineering Educators Department a three-semester M.Sc. course in MTW-SESEM (Management Technologies of Waters, Soft Energy Systems and Environmental Mechanics). Established in 2015, the M.Sc. in MTW-SESEM formally commenced its operations in July 2015, through a series of declarations of cooperation with universities and research centers in Greece and various European countries, and other institutions and renewable energy and water engineering firms. The multidisciplinary post university Master-level degree programme offers a 90 ECTS credit M.Sc. degree in MTW-SESEM with various renewable energy and water science directions, covering wind energy, hydropower, geothermal, wave energy, rational use of terrestrial and maritime waters and indigenous resources including oil and natural gas, environmental technologies, geopolitics, aesthetics, development policies etc. Each area of specialization at MTW-SESEM consists of a series of intensive 13 week modules per semester. Each series of modules includes and field trips to sites related to renewable resources activities. Students take an exam following the completion of each module and a final exam at the end of the semesters. The final degree requirement is a 30 credit Master's Thesis. Teaching staff of MTW-SESEM are professors and researchers from Greece, energy experts from engineering and energy consulting firms, and various international experts from research centers and universities in Europe. Tuition for the M.Sc. programs is 3.300 € for the full three-semester program. Many multidisciplinary important and compulsory components of the curriculum are combinations of theoretical and laboratory courses which aim to provide students with an understanding of the physical principles involved in renewable energy generation. To this end, laboratory-scale hydroelectric experiments were devised to develop and to demonstrate the hydropower and the Archimedean technologies of water screw turbines in low-head pico hydropower plants. The first step towards the creation of Educational Renewable Energy Screw Wheel Technologies for Pico Hydropower Generation and Sustainability is made by creating a reservoir-dam hydropower model (Figure 3).

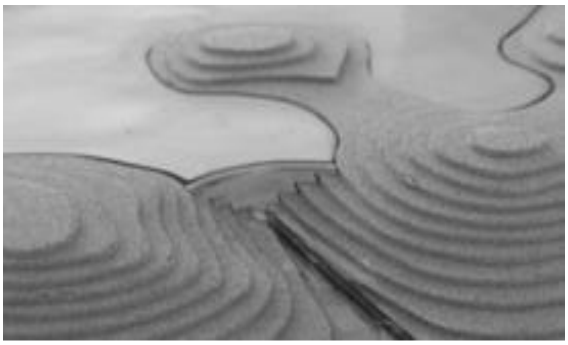

Figure 3. A model reservoir-dam hydropower

A series of laboratory-scale inclined axis Archimedean Screw Wheel devices have been designed and constructed under the supervision of the Austrian B.O.K.U. University and used in Austria and Greece, following the mainlines fixed from BOKU University by A. Stergiopoulou. Figure 4 shows optical information about three Archimedean screw rotors.

Figure 4. Three laboratory-scale inclined axis Archimedean Screw Rotors

The present effort deals with the design, construction and operation of a low head educational Archimedean Screw Wheel for Pico Hydropower Generation converter. The main aim of this effort is to bring a robust, easy-to-build and affordable screw technology. To achieve this objective, the present effort investigates the one-blade Archimedean Screw Wheel for its potential to be used as a good educational example of power converter and probably to be applied in bigger scales in the irrigation canals. The conception of the integrated educational Archimedean screw wheel for pico hydropower generation is also due to A. Stergiopoulou**.** A photorealistic artistic view of the Educational Renewable Energy Screw Wheel for Pico Hydropower Generation and Sustainability is given in Figure 5.

Figure 5. A. photorealistic artistic view of the Educational Renewable Energy Screw Wheel made by A. Stergiopoulou

The Archimedean screw rotor of this Educational Renewable Energy Screw Wheel for Pico Hydropower is built with locally simple materials based on PVC and cables. A steel axis was used in order to finish building of the screw rotor. The different steps of constructing the one blade Archimedean screw rotor and its characteristic dimensions are presented in the Figure 6.

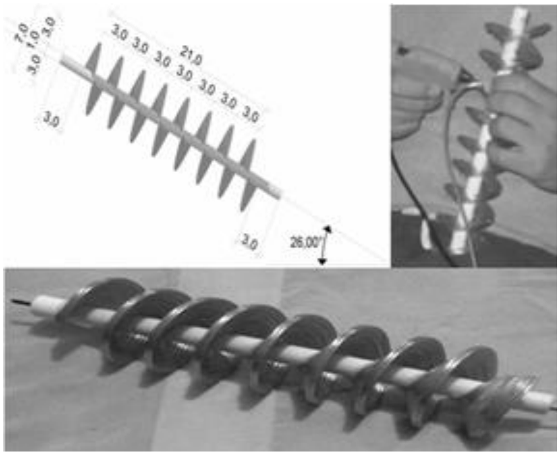

Figure 6. Different steps of constructing the Archimedean screw rotor and its characteristic dimensions

The screw rotor was easily installed without paying special attention to precision, particularly in position and eccentricity. Some characteristic views of the construction progress steps including the introduction of a Led lamp, for making sure that pico-hydropower electricity is really generated by this educational renewable energy screw wheel device are given in Figure 7.

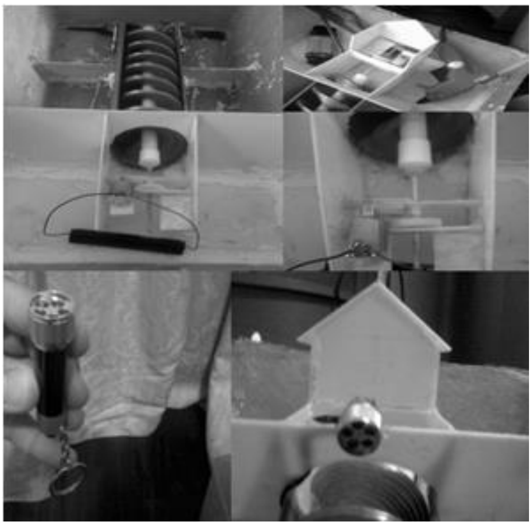

Figure 7. Characteristic views of the construction progress including the Led lamp

Views of the plastic shroud of the rotor and of the used pump are given in Figure 8. The flume tank of the whole system was build following GRP techniques. A bicycle generator was used and connected to the Archimedean screw through a simple gear-box made by gears from children toys. Views of the whole system flume tank and details concerning the various components including efforts for a better bleu aesthetic view of the flume infrastructure are given in Figure 9. An overall view of the complete whole Educational Renewable Energy Screw Wheel System for Pico Hydropower Generation, with details for the power house is given in Figure 10.

Figure 8. Plastic shroud of the rotor and two views of the pump

Figure 9. Views of the whole system flume tank and details concerning the components of

Figure 10. The Educational Renewable Energy Screw Wheel for Pico Hydropower Generation.

3. Measurements of the Hydrodynamic Performance Characteristics

The main components of the whole system acting as a real test rig are a pump, an overhead tank, pipelines, the Archimedean screw rotor, the side coverings, the shroud, the flume, the tail race tank. The dimensions of the whole system are 49cm x 34cm x 29cm. The weight of the whole system is 5,50 kg. The max volume capacity of the upper tank is 4,752 l. The max volume capacity of the lower tank is 3,960 l. The maximum volume of the flowing water that the test set up could safely handle was around 6,5 l. The diameter of the rubber pipe of the pump is 1,50 cm. The angle of orientation of the screw axis is 26^o. The diameter of the screw rotor is 3,50cm. The length of the screw rotor is 30cm. The diameter of the shroud is 3,75cm. The length of the shroud is 32 cm. Water flow was supplied through a pump having a satisfying nominal power capacity. To make sure that pico hydropower electricity is really generated by this educational renewable energy screw wheel device, not only a led lamp is installed on bicycle generator is on, but also pico hydropower electricity is measured by using two multimeters to show how much current and voltage are generated. The rotation speed measurements were made with an electronic handle rotation meter (Figures 11).

Figure 11. Current and voltage measurements with two multimeters and rotation speed measurements with an electronic handle rotation meter

Views of typical measurements in the MTW-SESEM M.Sc. classroom of the produced voltage and current with two polymeters are given in Figure 12. A series of pico hydropower performances measurements was realized in the classroom of MTW-SESEM M.Sc. By using a water volume 7500ml, as an example of these experiences, with measurement of rotation with tachometer get 187 RPM on turbine, this educational pico hydro turbine can generate power 6,36 mW, which consist of 5.3 mA current and voltage 1.2 volt. Results of these educational experiment are very promising because better installing of this turbine should increase its performance. Figure 13 gives the evolution of the measured rotation speeds N(RPM) following increase and diminution of water flow V(ml).

Figure 12. Measuring voltage and current (f.e. V=1.210 V and I=5.28 mA)

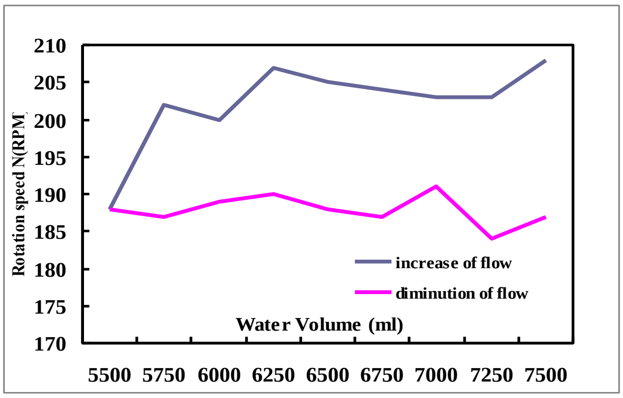

Figure 13. Evolution of the measured rotation speeds N(RPM)

Next figure gives the obtained results of the measured hydrodynamic power P(mW) in function of the increase and diminution of water flow V(ml).

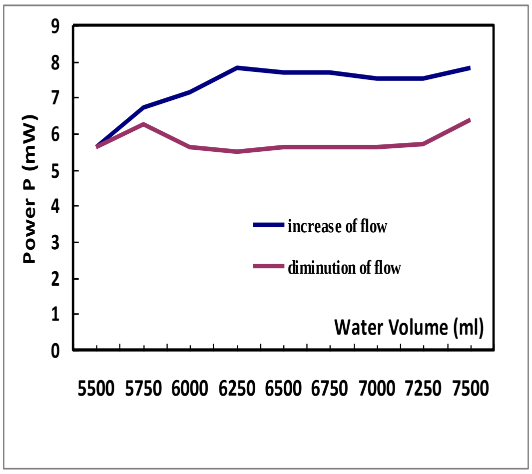

Figure 14. Evolution of the hydrodynamic power P(mW)

Figure 15 is given the obtained hydrodynamic torque T(N.m) in function of the increase and diminution of water flow V(ml).

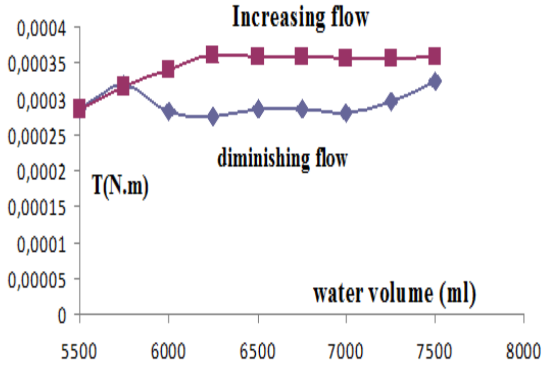

Figure 15. Evolution of the hydrodynamic torque T(N.m)

4. Conclusion

Valuable information about the hydrodynamic performance characteristics of the MTW-SESEM M.Sc. educational screw wheel turbine simulating pico hydroelectric generation was collected through the experiments. This educational screw turbine is designed and built successfully under the supervision of the Austrian B.O.K.U. University, with locally simple material and this turbine can generate pico hydropower performances. By considering equipment and measurement tools used, the preliminary educational results are very promising to be continued. Archimedean screws, including the proposed here educational renewable energy screw wheel technology for pico hydropower, are a new type of turbines not only in Greece but also in all countries throughout the world, having a number of advantages over conventional turbines (e.g. they require very little fish and debris screening, their installation costs can be lower than comparable Kaplan turbines, they are mechanically simple etc). The possibilities of scaling-up the proposed here educational screw wheel technology for pico hydropower generation, by following the similarity methodology of the Buckingham's π-theorem, are very promising and could give a series of innovative new Archimedean turbines in bigger scale to be installed in low-head water canals and rivers in order to operate as real hydropower plants. More research needs to be done, in the field of the present Educational Renewable Energy Screw Wheel for Pico Hydropower Generation, including the hysteresis in the performance curves observed during the classroom measurements, before this educational pico screw turbine is used in one or more low head sites in remote areas.

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