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COMPARATIVE STUDY OF POWER TAKE-OFF UNITS OF OWC BASED WAVE ENERGY POWER PLANTS

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Abstract:

Ocean wave energy is one of the most abundant sources of renewable energy in the world. Majority of the wave energy extracting devices are based on oscillating water column (OWC) technique. Onshore OWC based wave energy power plants have shown great promise in converting raw wave energy into useful electricity in different parts of the world. So far most of the wave energy projects are using the Wells turbine as power take-off unit. But Wells turbine has some inherent disadvantages associated with it. On the other hand the Impulse turbine with fixed guide vanes has presented far better results than the Wells turbine. In this paper comparative study is presented that concludes on to the selection of impulse turbine with fixed guide vanes as power take-off unit for ultimate design of an onshore OWC based wave energy power plant.

Keywords: Wave Energy, Impulse Turbine, Oscillating Water Column.

Introduction

Energy is the indispensable want of life. From earliest times it can be seen that energy has been used in three forms; low temperature heat for comfort of human beings, force required for motion and high-temperature heat in order to work on materials and lightening purposes. These forms of energy are still in extensive use. After industrial revolution, there was need of more energy and hence extensive use of fossil fuels started to meet the growing energy demands [1].

Being inexpensive and easily available, the fossil fuels lead towards the wide usage in machinery. However, fossil resources are limited and are rapidly depleting. Therefore, there is a need to exploit renewable energy resources. The various types of renewable energy resources are solar, wind, geothermal, hydel, biomass, tidal and wave energy of ocean.

Wave energy is generated by wind passing over stretches of water. As the wind is originally derived from solar energy, it can be taken as to be the high-density form of solar energy. The World Energy Council estimates that a total of 2TW of energy could be harnessed from the world's oceans, the equivalent of twice the world's electricity production. Among the renewable energy resources, ocean wave energy is an abundant, persistent and clean source of power and is available round the clock. Wave energy technology is an emerging technology [2, 3, 4].

Currently world is facing very serious energy crisis. Especially in Pakistan the situation regarding energy is the worst. The shortage of the energy is badly affecting the economy of the homeland. In this scenario wave energy resource should be exploited to meet the energy demand. Pakistan is gifted with long

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coastline by Allah. It is estimated that the wave energy of intensity 10-12 kW/m of wave front is incident on Pakistani coastline.

Wave Energy Technology

A number of device concepts have been used to capture wave energy over the period and to convert it into useful form of energy. Practical application of different techniques or device concepts in prototypes in the sea indicated that only one technique i.e., the Oscillating Water Column or OWC could be thought of near to full development or ripeness [5, 6].

Oscillating Water Column (OWC)

The OWC based wave energy power plant consists of a concrete or steel structure which is partially submerged in the sea water. This structure has an opening towards the sea below the water line, therefore enclosing air above the column of water as shown in Fig. 1. When waves of sea water travel and reach the structure, they cause the water column inside the chamber of the structure to rise and fall. This rise and fall i.e., oscillation of water column causes the air to exhale and inhale. The exhaling and inhaling air is allowed to pass to and from the atmosphere through a self-rectifying turbine which drives an electric generator [7, 8, 9, 10].

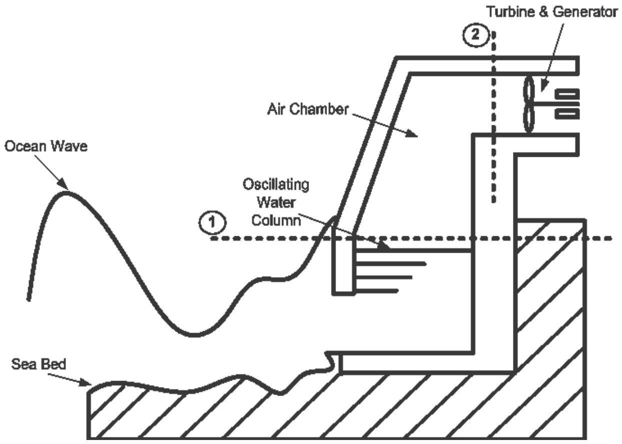

Figure 1. Schematic of onshore OWC based wave energy power plant [10]

The self-rectifying turbines are those turbines that are capable to rotate in one direction only irrespective of the direction of airflow passing over them. This characteristic of self-rectifying turbine is due to their specially designed symmetric blade profiles. Over the period of time many different types of turbines have been developed. Among them the two prominent self- rectifying turbines used for wave energy power conversion are discussed below [11].

The Wells Turbine

Dr. A.A Wells of Queen’s University, Belfast, UK, invented the Wells turbine in 1976, (Figure 2). This turbine is an axial flow self- rectifying turbine and is suitable for wave energy conversion in an oscillating water column. This turbine has a symmetric blade shape commonly based on NACA four digit profiles. It works on the basic aerofoil theory. The lift over the aerofoil creates a tangential torque component that makes the turbine to rotate. It is a high-speed turbine and operates between 700 to 1500 rpm.

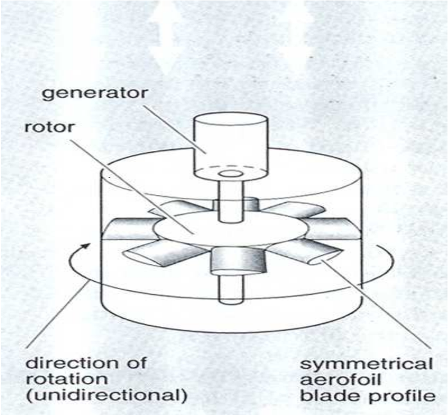

Figure 2. The Wells turbine schematic diagram [11]

Several reports describe the performance of Wells turbine. According to these reports it is established that the Wells turbine has some inherent disadvantages that are narrow range of flow rates at which it operates at useful efficiencies, poor starting characteristics, high speed operations and consequent noise and high axial thrust [11]. So far some new versions have been tried to overcome these weak points. Some other types of the Wells turbine are given in the following.

(i) Wells turbine with guide vanes (WTGV) Fig. 3
(ii) Turbine with self-pitch-controlled blades (TSCB) Fig. 4
(iii) Biplane Wells turbine with guide vanes (BWGV) Fig.5

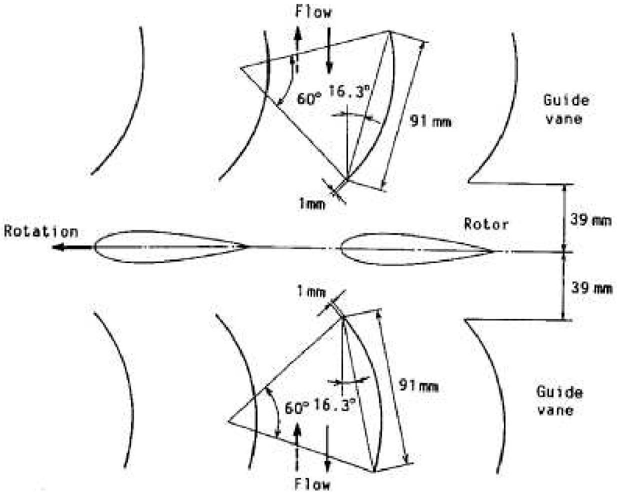

Figure 3. Wells turbine with guide vanes (WTGV) [12]

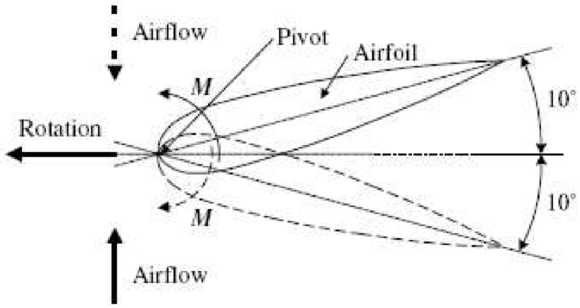

Figure 4. Turbine with self-pitch-controlled blades (TSCB) [12]

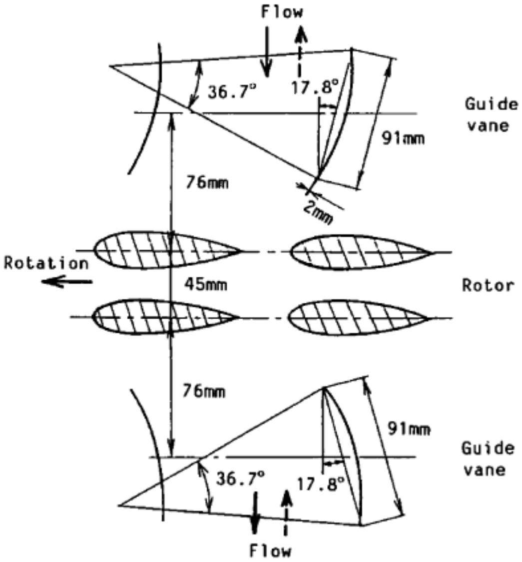

Figure 5. Biplane Wells turbine with guide vanes (BWGV) [12]

As mentioned earlier the Wells turbine is the most commonly used self- rectifying turbine on OWC based wave energy power plants so far, but its inherent disadvantages led to the shift towards other self-rectifying turbines.

The Impulse Turbine

By the time of introduction of the Impulse turbine by Kim and his team, in 1988 , the research on both turbines was in progress in Japan. The most important contribution in this research work was added by Professor T. Setogouchi and his team at Saga University of Japan in Collaboration with other Universities and Institutions of Japan, Asia and Europe.

Fig. 6 shows the rotor of the Impulse turbine. This rotor is surrounded by two sets of guide vanes on either side. Under the action of these two sets of guide vanes the turbine becomes capable of rotating in one direction only in a bidirectional air flow.

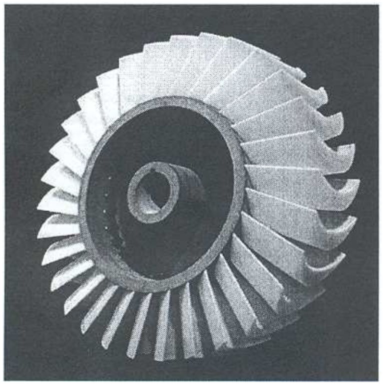

Figure 6. Rotor of the Impulse turbine [11]

A number of Impulse turbines for the wave power conversion have been presented so far. Among them three important impulse turbines are as follows.

1. impulse turbine with self-pitch-controlled guide vanes (ISGV) (Fig. 7)
2. impulse turbine with self-pitch-control linked guide vanes (Fig. 8)
3. impulse turbine with fixed guide vanes (IFGV) (Fig. 10)

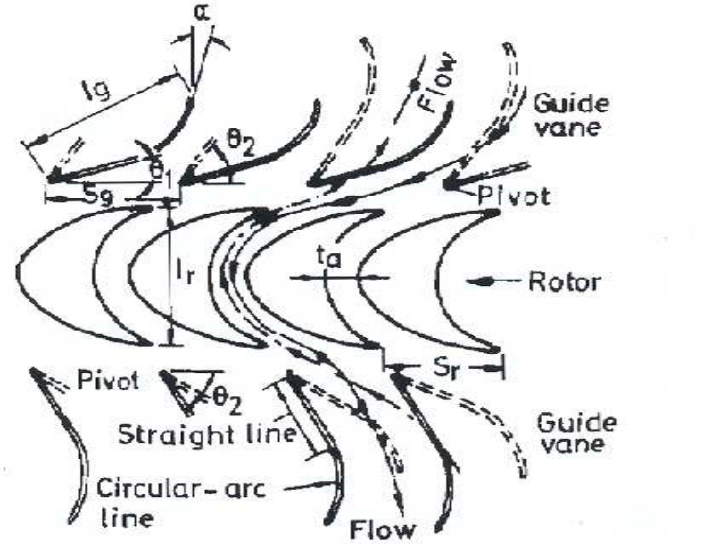

Figure 7. Impulse turbine with self-pitch controlled guide vanes [12]

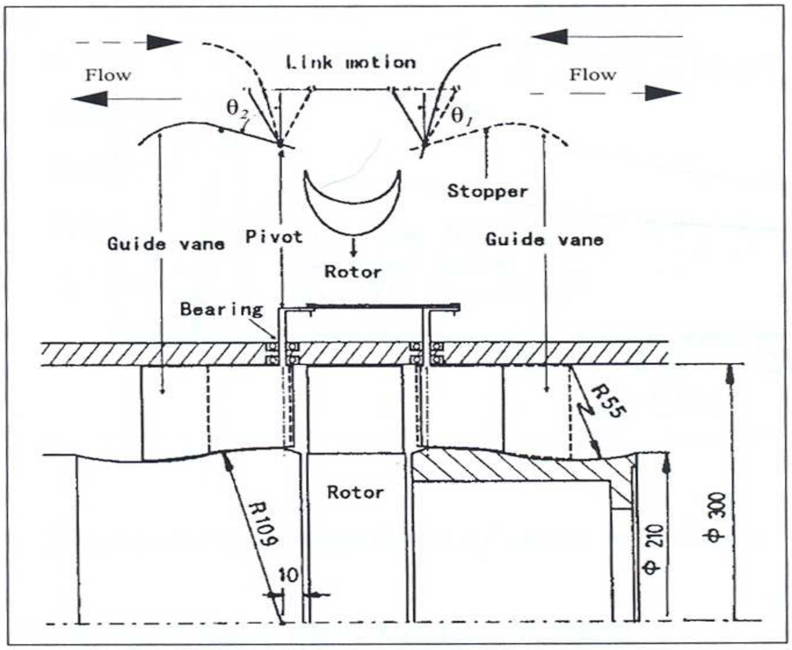

Figure 8. Meridional section of Impulse turbine with self-pitch-control linked guide vanes [12]

For same guide vane geometry parameters, other than links, as used for the Impulse turbine with self-pitch-controlled guide vanes it was found that the efficiency of turbine with linked guide vanes was superior (Fig.9).On the other hand this configuration has its own disadvantage of enlarged maintenance due to presence of larger number of moving parts. Consequently this lead towards the impulse turbine with fixed guide vanes.

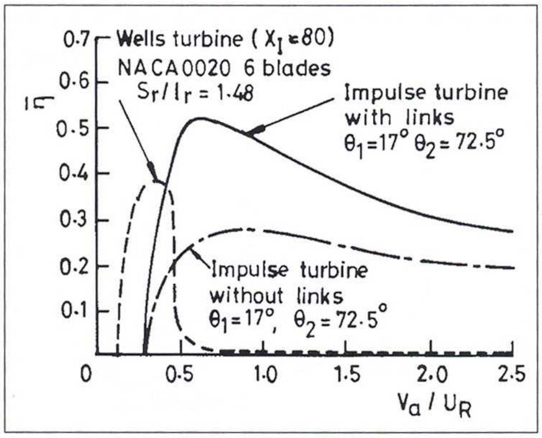

Figure 9. Comparison of mean efficiency [11}

Impulse Turbine with Fixed Guide Vanes

Due to large number of moving parts in complex design of moving guide vanes with links frequent maintenance was the major problem. Therefore, it was proposed by the researchers that if the guide vanes were fixed on both ends at an optimum angle, this problem could be overcome. Although this configuration will affect the peak efficiency of the turbine but the simple design can compensate for the slight drop in the overall performance. In this configuration, there are two rows of symmetrically placed fixed guide vanes on both sides of the rotor with a fixed inlet/outlet angle Fig.10.

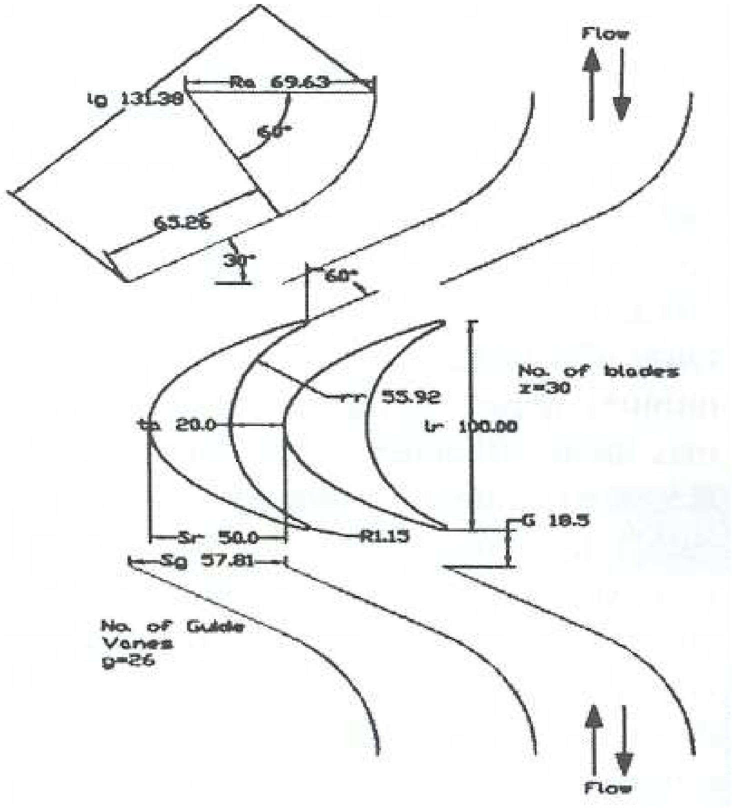

Figure 10. Impulse turbine with fixed guide vanes [11]

Efficiency Comparison of Impulse Turbine with Fixed Guide Vanes and the Wells Turbine

Comparison of both Wells and Impulse turbines with similar tip diameter of 0.6m and a hub to tip ratio of 0.6 under regular flow conditions is presented here. The experimental data used for the Wells and Impulse turbines for this analysis is taken from the work carried out by Bajeet, 2001[13] and Khaleeq, 2002 [11] respecively.

For the comparison of the two turbines, experimental data under uni-directional steady flow conditions were used. The data for the Impulse turbine was based on a constant rotational speed of 350 rpm and for the Wells turbine, at a constant rotational speed of 1700 rpm.

The plot shown in the (Fig. 11) gives the comparative efficiency curves for both turbines based on experimental data. It can be observed that the Wells turbine is giving a peak efficiency of 74% as compared to 48.73% achieved by the impulse turbine. It can also be observed that the Wells turbine stalls at a flow coefficient of 0.38 whereas the impulse turbine keeps on giving useful output for higher flow coefficient.

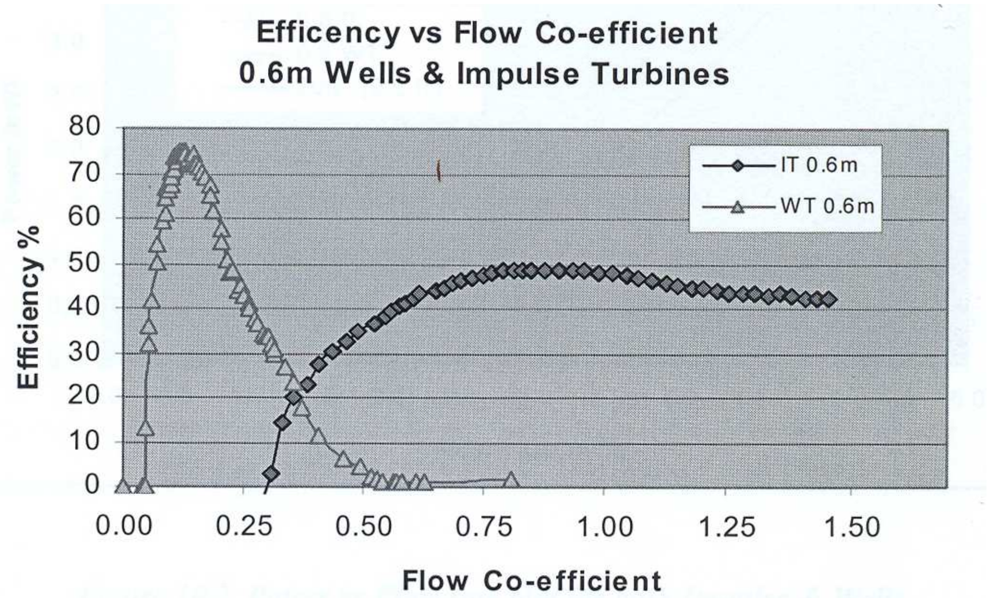

Figure 11. Efficiency Comparison under regular flow conditions [11]

Therefore, it can be said that the Impulse turbine has a far better range of efficient and stable operation as compared to the Wells turbine. Its wide operational range compensates for its lower maximum efficiency (48.73% compared to 74% for the Wells turbine). Therefore, it is believed that the Impulse turbine is capable of coping up with high intensity waves, the conditions where the Wells turbine is believed to stall. This also shows the Impulse turbine can operate at lower rotational speed whereas the Wells turbine is a high speed turbine and therefore has its disadvantages from maintenance problems as well as high noise operation. Although, this particular configuration of the Wells turbine showed that it is self-starting, as compared to the other configurations, the Impulse turbine is inherently self-starting, which gives it another edge over low-solidity vaneless Wells turbines [11].

Comparison of conversion efficiencies and starting characteristics of Impulse type and Wells type turbines

An important study was carried out by Setoguchi and Takao in 2005 [12] to compare the performances of self rectifying turbines under irregular wave conditions which are prevailed in real sea conditions. The performances were evaluated numerically.

In Fig.12 comparison of conversion efficiencies of five above mentioned turbines is presented. Conversion efficiency may be defined as the product of the efficiencies of the air chamber and the turbine. It can be seen that conversion efficiency for impulse type turbines is higher than the Wells type turbine.

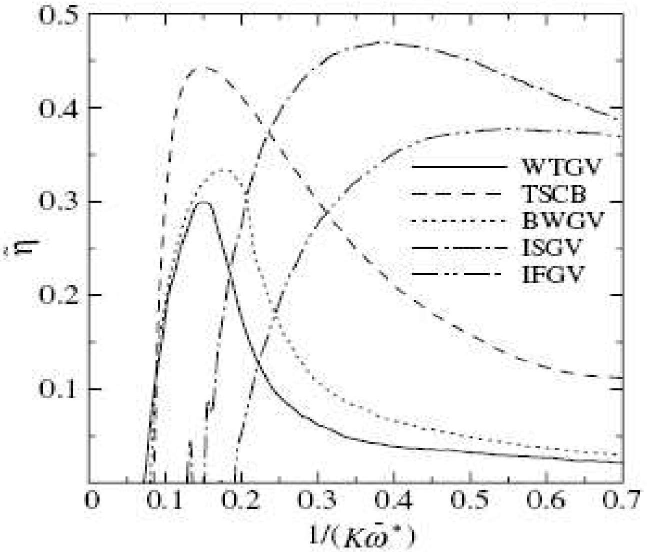

Figure 12. Comparison of conversion efficiency of wave energy [12]

In Fig.13 starting characteristics under irregular sea conditions are presented. Analysis of the figure shows that the impulse turbine can start in short time than the Wells turbine. This means that the generating time of a generator with the impulse turbine is more than that of the Wells turbine. Also the operational speed of the impulse turbine is less than that of the Wells turbine which is helpful in noise reduction. It can be concluded that the impulse turbine is superior to that of the Wells turbine in starting and running characteristics [12]. Summary of the comparison of the two turbines can be presented in the tabular form as given in table 1.

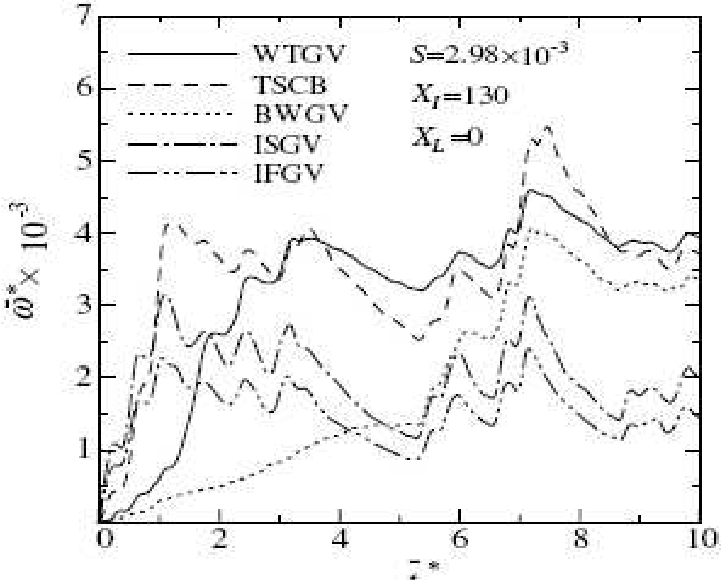

Figure.13. Starting characteristics under irregular sea conditions [12]

Table 1. Summary of comparison

Sr.No.	Wells Turbine	Impulse Turbine
1	High operating speed	Low operating speed
2	High axial thrust	Low axial thrust
3	High noise	Low noise
4	Low solidity	High Solidity
5	Poor starting characteristics	Good starting characteristics
6	Narrow range of flow rates	Wide range of flow rates
7	Delivers maximum output /efficiency at a particular value of flow coefficient	Delivers useful output/efficiency at wide range of flow coefficient
8	It stalls at high flow coefficients	There are no stall conditions
9	Can not cop up with high intensity waves	Can cop up with high intensity waves
10	Poor range of efficient and stable operation	Better range of efficient and stable operation
11	Poorer starting and running characteristics	Superior starting and running characteristics

Conclusions

It can be concluded from the above presented study that the impulse type turbines are superior to the Wells type turbines. The Wells turbine has high operational speed, therefore produces more noise while the impulse turbine has low operational speed which is merit in noise reduction. The study also indicates that the conversion efficiency of the impulse type turbines is superior to the Wells type turbines. Starting and running characteristics of the impulse type turbines are better than the Wells type turbines. The Wells turbine delivers maximum output or efficiency at a particular value of flow coefficient above which it stalls. The impulse turbine delivers useful output or efficiency at a wide range of flow coefficient and there are no stall conditions. The Wells turbine does not respond well in high intensity waves, whereas the impulse turbine performs well in this situation.

If the performance of the impulse turbine with self-pitching guide vanes is compared with the performance of the impulse turbine with fixed guide vanes it is found that the former is superior to the later. But on the other side it is seen that due to presence of larger number of moving parts in self-pitching guide vanes configuration frequent maintenance is problematic. This difficulty can be mitigated by compromising on a little reduced efficiency or performance by adopting the impulse turbine with fixed guide vanes. Reduced maintenance will result in longer operational life and less cost. Therefore, the impulse turbine with fixed guide vanes is a better choice, as power take-off unit for an onshore OWC based wave energy power plant, in comparison to the Wells turbine. The impulse turbine with fixed guide vanes has a far better range of efficient and stable operation as compared to the Wells turbine. It delivers useful efficiency over a wide range of flow coefficient.

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GUIDELINES AND INFORMATION FOR AUTHORS (Revised)

General

Papers may be submitted any time throughout the year. After having received a paper it is sent to three referees, at least one from a technology advanced countries. Papers reviewed and declared fit for publication before 31 December are published next year before 31 March every year. Papers must be submitted on a CD with FOUR Hard copies to the editor Technical journal, University of Engineering and Technology Taxila. Soft copy by e-mail to the following address is preferred.
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Authors are required to read the following carefully for writing a paper.

Text

Text should be type-written with M.S word, Arial Font size 10.at single space and with margins as 1.5 inch top,1 inc right,1 inch left and 1 inch bottom, on an A-4 size, paper. The title page should include; the title; the name/names of the authors and their addresses, an abstract of about 200 words and keywords followed by the introduction. The text of the paper may be divided into introduction, methodology/Analysis results and discussion, conclusion, references and acknowledgment (if any). All pages should consist of single columns text.

Length

Research paper should not exceed 15 pages as per specifications given above.

Elements of Paper

The basic elements of paper are listed below in the order in which they appear: Title, names of the author and affiliations, Abstract, Body of paper, Acknowledgments, Nomenclature, references, Appendices.

Title

The title of the paper should be concise and definitive.

Names of Authors and Affiliations

Names of authors should consist of first name (or initial), middle initial and last name. The author affiliation should consist of his full address.

Abstract

An abstract up to a maximum of 200 words should open the paper. The abstract should give a clear indication of the objectives, scope and results, the abstract text may be organized to include the background, methods, results and conclusions.

Keywords

Keywords should be included on a separate line at the end of the abstract.

Body of the Paper

Body of the paper may include introduction and literature review, materials and methods, modeling/experimentation, results-discussions and conclusions.

Originality

Only original contributions to engineering and Science literature should be submitted for publication. It should incorporate substantial information not previously published.

Accuracy

All the technical, scientific and mathematical information contained in the paper should be checked with great care.

Use of SI Units. Preferably SI units of Measurements be included.

Mathematics

Equations should be numbered consecutively beginning with (1) to the end of the paper. The number should be enclosed in parentheses (as shown above) and set flush right in the column on the same line as the equation. This number then should be used for referring the equation within the text. Equation may be referenced within the text as “E q. (x)”.”When the reference to an equation begins a sentence, it should be spelled out fully, as “Equation (x).in all mathematical expressions and analyses, symbols (and the units in which they are measured) not previously defined in nomenclature should be explained.

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All figures (graphs, line drawings, photographs, etc.) should be numbered consecutively and have a caption consisting of the figure number and a brief title or description of the figure. This number should be used when referring to the figure in the text. Figure references should be included within the text in numerical order according to their order of appearance. Figure may be referenced within the text as “Fig.-x”.When the reference to a figure begins a sentence, the abbreviation “Fig,” should be spelled out e.g.,” Figure-x”

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All tables should be numbered consecutively. Tables should have a caption consisting of the table number and brief title. This number should be used when referring to the table in text. Table references should be included within the text in numerical order according to their order of appearance. Table should be inserted as part of the text as close as possible to its first reference.

Acknowledgments

All individuals or institutions not mentioned elsewhere in the work who have made an important contribution should be acknowledged.

References

Within the text, references should be cited with name of the author and year in parenthesis. The reference list will be arranged alphabetically.

Example

Chamber (1959) has described a method and Wormleaton (2006) used this method. In case of two authors, name of both the authors will appear with year. For example Khan and Ghumman (2008) studied hydrodynamic modeling for water-saving strategies in irrigation canals. In case of three or more authors it will be cited as: Ghumman et al. investigated use of numerical modeling for management of canal irrigation water in case of continuous references, the references may be separated by comma”,” See the list of sample references.

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References to original source of the cited material as given above as sample reference should be listed together at the end of the paper, footnotes should not be used for this purpose. References should be arranged in alphabetic order. Each reference should include the last name of each author followed by his initials.

(1) Reference to journal articles and paper in serial publication include :Last name of each author followed by their initial, Year of publication, Full title of the cited article, Full name of the publication in which it appears, Volume number (if any) in boldface, Issue number (if any) in parentheses, Inclusive page number of the cited article.

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Sample references

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