Кінетична енергія – це енергія, вироблена за рахунок швидкості руху води в річках. Енергія швидкості руху води може бути ефективно реалізована як заміська електростанція. Це дослідження проведено експериментально в лабораторних умовах. Випробовувана турбіна являє собою кінетичну вертикальну турбіну, оснащену вісьмома лопатями. В даному дослідженні спостерігали за поведінкою руху води і лопатей в турбіні.

Візуальне випробування – це випробування шляхом спостереження за рухом лопатей турбіни і поведінкою води в області турбіни. Візуальне випробування показує, що є причиною низької продуктивності і нестабільного обертання турбіни.

Як видно з візуального спостереження, вода не повністю влучає в лопать турбіни. Час відкриття лопаті турбіни трохи запізнилий, тому вода не може повністю підштовхнути поверхню лопаті. У певному положенні лопаті потік води не потрапляє в область між двома лопатями, що призводить до слабкого поштовху лопаті. Це означає, що відбувається зниження крутного моменту турбіни. З цих пояснень випливає, що дані обмеження є причинами нестабільного обертання турбіни. Для поліпшення продуктивності турбіни пропонується збільшити число лопатей турбіни. Чим більше лопатей, тим менше площа між двома лопатями і тим ефективніше потік води штовхає лопать турбіни. Обертання турбіни буде більш стабільним, а продуктивність турбіни, безсумнівно, буде вище

Ключові слова: енергія води, потенційна енергія, поворотна лопать, вертикальний вал, кінетична турбіна, візуальне спостереження

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MOVABLE BLADE VERTICAL SHAFT KINETIC TURBINE VISUAL OBSERVATION

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1. Introduction

Electrical energy needs can be met by utilizing available energy sources. Water is a great source of energy. Areas with hilly topography with many mountains, strongly support the flow of large rivers and waterfalls. Natural resources can meet electricity needs by converting natural energy into electrical energy. The potential for hydropower can be divided into two categories of water potential [1]. The first is large-scale water potential and the second is small-scale water potential. In this case the suitable small-scale potential is turbine kinetic. Research on this small turbine kinetic is still very limited.

Therefore, studies are devoted to the water flow behavior in the turbine area. Is it true that the water flow produces a boost in the turbine blade. This force will generate momentum which will later be converted into a turbine torque.

2. Literature review and problem statement

Indonesia has a great potential for new and renewable energy reserves, but has not implemented to its full. Hydroelectric power plants in Indonesia have reached around 4,200 megawatts (MW), or around 5.5 percent of the available water potential. The priority of the 2010–2014 National Research Program, in the field of energy alternatives, is to increase the use of renewable micro-hydro energy. The potential status of renewable energy is microhydro energy utilization of 17.22 % or 86 MW of the available 500 MW potential.

Some researchers conduct a research to improve the kinetic turbine performance. In [2], a research was done to observe the effect of steering flow angles on cup-bladed kinetic turbine performance. The study [3], reported a research on a dual nozzle cross flow turbine and electrical power generation was also conducted. The results of this study are that cross flow turbines with two nozzles have a higher power and higher efficiency compared to turbine cross flow with a single nozzle. Another research in [4] was conducted to determine the prototype of a double wheel kinetic turbine as a Rural Electric Power Plant. The purpose of this study is to minimize the water stream backflow. The results of this study indicate that the maximum load that occurs in the second runner occurs at a water flow rate of 2 and 2.5 liters/second.

There is another research observation done [5] using turbine hunters with vertical axes. The shape of the turbine blade used in this study is a semicircular type. The turbine blade is mounted on the turbine rotor with a hinge. The torque generated from this type of turbine will rotate the turbine and can generate power to be converted into electricity by a generator. The work [6] is an extended research done to determine three-dimensional effects on the performance of tidal current turbines with vertical axis turbines. Just like the research before, the blade used is made of a semicircular sheet steel plate and uses a hinge. In addition to the type of blade, the angle of water entrance will also affect the turbine rotation. The water flow will not always be linear when the turbine rotation increases and the direction of the water flow angle with a constant speed in generating maximum rotation.

The report in [7] is a research on a savonius water turbine that was investigated to obtain the turbine performance using one and two steering blade plates. The steering blade serves to direct the water flow straight to the blade right side. The paper [8] is reporting a research conducted to test the performance of a vertical shaft hinged arc blade kinetic turbine. This turbine will be observed also in the analysis of the movement behavior of the water flow in the turbine chamber to find out some of the constraints of this turbine performance. This turbine design is very simple and can be produced and used in remote areas. The paper [9] proposed a study to obtain the maximum Turgo Pico-Hydro Turbine performance by using a single jet and a low turbine head of 3.5 m to 1 m.

In [10], a study was executed, to determine the performance of the modified savonius turbine using two steering plates to direct the flow of water to hit the turbine blade straight ahead. A research was also done using the Response Surface Methodology to optimize a vertical shaft kinetic turbine as seen in the paper [11]. The kinetic turbine in this study uses a vertical axis turbine. It is expected that the use of this vertical shaft can facilitate the installation of an electric generator. The turbine uses a bowl-shaped blade and is attached to the turbine disk using a hinge. The use of this bowl-shaped blade is expected to distribute the water mass through the blade curvature and rise again gently in all directions and can withstand the pressure of the water flow to increase the tangential strength produced. So that the torque produced will increase and produce an increase in turbine performance.

Although some of the studies mentioned above are very supportive of improving the hinged blade turbine kinetic performance, but it seems that the turbine kinetic performance improvement is not as large as expected [8]. Based on theory and some research that has been done to support the turbine performance improvement, turbine kinetic performance should be far better than what is obtained from the research [8]. It is suspected that there are some irregularities that occur in the turbine area that do not work as expected. One of the reasons to do this extended research is the low momentum generated by the water flow pushing the turbine blade.

In this study, experimental tests have shown a weakness in the kinetic turbine performance. This experimental research can only test and record the results. The results obtained are evaluated by doing calculations based on the existing formulas. So that if there is a low turbine performance the researchers cannot identify the actual problem accurately.

As is known, turbine performance is determined by the amount of torque produced. While the torque produced is a conversion of the momentum generated by the water impulse in the turbine blade. The thrust on the turbine blade is the force produced by water flow on the blade. These statements are of ideal conditions. So the main focus of producing turbine torque is water flow that contains kinetic energy. If what happens is different or the resulting value is smaller, it needs to be observed whether that is the cause. The most appropriate way, which has never been done by researchers, is to look at the behavior of water in the turbine area. From the behavior of water in the turbine, it is expected, a result of the main causes of low turbine performance. The behavior of water in generating performance is certainly related to the turbine construction, turbine blade shape and in this study is the behavior of hinges in the process of opening and closing the blade. Whether the turbine blade opening and closing are about the right time.

With the observations regarding the water flow behavior, all events in the turbine area can be clearly seen. Every movement, whether a water flow or a turbine part doesn't work properly, can be easily detected. Researchers could be easy to make a decision on what to do, to solve the actual problem. For example, making a modification of turbine parts that are not working as expected. Modify the water flow rate direction, to get the optimum turbine performance.

To solve this problem, it is necessary to investigate what actually happens in the turbine area. Therefore, research with visual observation is expected to find out and hopefully could solve the problem.

3. The aim and objectives of the study

The aim of this study was to investigate the kinetic turbine performance after the turbine blade modified with a hinge.

To achieve the set aims, the following objectives have been set:

– to assess performance increase on the kinetic turbine with a hinge blade, compared to the conventional kinetic turbine;

– to see the maximum power produced by this kinetic turbine;

– to investigate the maximum kinetic turbine hinged blade efficiency;

– through a visual observation, does the blade move at the hinge as desired.

4. Material and Methods

4. 1. Kinetic turbine

Kinetic turbine is a simple prime mover to generate electricity. This kind of turbine is used in rural areas. It is expected that this turbine could be easily operated. A lot of research was conducted to raise the turbine performance.

As mentioned above, that turbine, which will be observed in the study, has been tested for its performance in the Brawijaya University (Indonesia) fluid mechanics laboratory. In this test, what was done was to record all the performance variables of the turbine. The parameters recorded are water flow rate, turbine rotation (RPM), turbine torque and water velocity. This turbine has a drum diameter of 120 mm. The turbine blades have a specification of 110 mm chord length and 110 mm blade height. The number of blades is 8 pieces and all blades connect with a drum with a hinge. Each blade can open and close freely around the hinge pin before positioned perpendicular to the drum and stopping at a stop. The aim of using this hinged system is to prevent the water back flow to reduce the turbine power [5, 6]. These whole turbine test installation dimensions were taken based on the geometrical similarities.

It is quite clear that each blade will get two dynamic processes in full rotation, namely the opening and closing process.

But it is difficult to determine accurately when these two processes are triggered or resolved by a certain water flow rate only with theoretical analysis.

This turbine is tested with several variations of water flow rates, namely 35 m^3/s, 40 m^3/s, 45 m^3/s and 50 m^3/s. These water flow rate values were chosen to adjust with the duct available in the laboratory. The other parameters are the turbine breaking (similar to a prony break) to measure the turbine torque. From the turbine torque, the turbine horse power could be calculated.

4. 2. Kinetic Turbine Power

The power of a kinetic turbine is determined by the amount of power produced by the flow. The kinetic turbine power is calculated using the equation below:

$$P_a = \frac{1}{2} \cdot \rho \cdot Q \cdot v^2. \quad (1)$$

Using the continuity equation $Q = A \cdot v$ so that the equation becomes:

$$P_a = \frac{1}{2} \cdot \rho \cdot A \cdot v^3, \quad (2)$$

with P_a – water power (Watt); ρ – specific weight (kg/m^3); A – cross sectional area (m^2); v – water flow velocity (m/s).

The equation below is used to determine the turbine break horse power:

$$P_t = T \cdot \omega, \quad (3)$$

where $T = F_t \cdot R$ and $\omega = (2 \cdot \pi \cdot n)/60$; P_t – turbine power (Watt); T – torque (Nm); ω – angular velocity (Rad/s); R – pulley radius (m); n – turbine rotation (rpm); F_t – tangential force (N).

The kinetic turbine efficiency is determined from the ratio between the input water power and the power turbine power:

$$\eta = \frac{P_t}{P_a}, \quad (4)$$

where P_t – turbine power (Watt); P_a – water power (Watt).

4. 3. Experimental installation

In this study, the turbine was submerged in a research duct. The duct size was limited by the duct cross sectional area. Convergent parts are installed upstream to accelerate the water flow entering the turbine. The turbine blades are the standard curved blades (Fig. 1) and have the same distance around the drum.

Fig. 1. Turbine Model

To facilitate the installation of turbines in the duct, the turbine is prepared in a carrier (Fig. 2). The carrier, with the turbine model load on it, would be easily placed/submerged in the turbine test duct channel.

Fig. 2. Turbine mounted on a carrier

During the observation, a water flow regulator (Fig. 3) is used to control the water flow rate, especially for the water flow rate variation regulation.

The turbine position in the duct could be seen in Fig. 4.

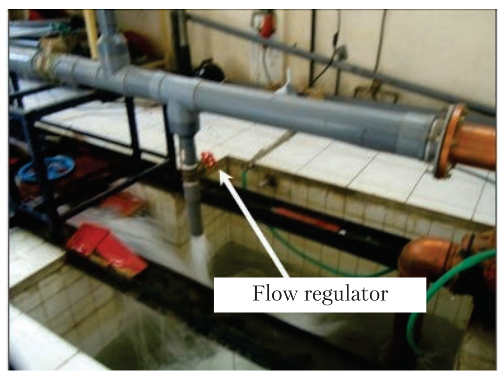

Fig. 3. Water Flow Rate Regulator

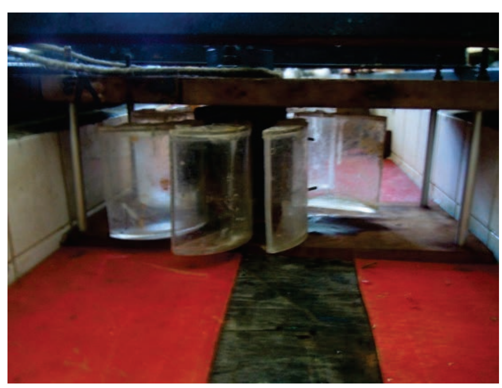

Fig. 4. Turbine positioned in the duct

The turbine rotation (RPM) was also measured for every turbine parameter variation (Fig. 5).

Turbine torque is obtained from a breaking parallel loading system (Fig. 6).

Regulating the water flow rate can be monitored from an equipment mentioned as the water flow rate indicator (Fig. 7).

Fig. 5. RPM measurement

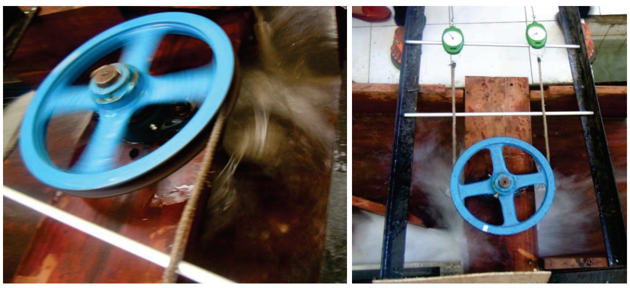

Fig. 6. Torque measurement

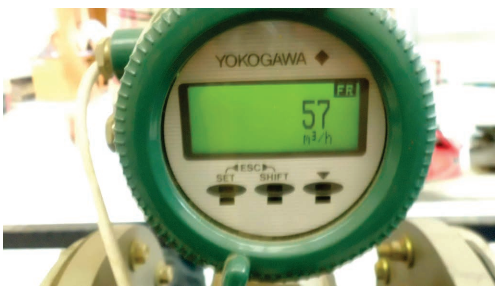

Fig. 7. Water flow rate indicator

4. 5. Experimental study by recording water and blade behavior

As mentioned above, this research is observing the turbine blade and the water flow movement. To observe in this way, a camera is needed.

The camera used is a Nikon Coolpix S8000 14.2 megapixel digital camera with 10x Optical Vibration Reduction VR0 zoom and 3.0 Inch LCD (Fig. 8). This camera is used to capture instantaneous images of turbines running at different rotational speeds.

Fig. 8. Camera (Nikon Coolpix S8000 14.2MP), Japan

The maximum resolution of the camera is 14.2 megapixels, the speed at maximum resolution is 1,000 pps, and the maximum recording duration is 1.92 s. To observe the opening and closing points directly, the camera is placed above the turbine duct (above the turbine carrier), so the behavior of the water flow rate and blade movement can be recorded directly.

This turbine has been tested for its performance, under a number of conditions, variations in parameters for obtaining turbine performance. In this advanced research, turbine behavior will be observed in more detail by taking pictures of blade movements and water flow rate behavior in the turbine. This advanced research is needed to see how the turbine blade moved and how is the water movement behavior in the turbine chamber, in accordance with the research assumption that has been established.

One reason, for this study, to observe the turbine blade behavior, movement and water flow rate movement, is that the unstable turbine rotation and the low turbine efficiency were predicted from the theoretical estimates.

In summary, the implementation of this research is, taking video pictures as long as the turbine operates at a certain water flow rate, certain turbine turns and certain loading.

5. Results

5. 1. Research results from the laboratory experiment

From the laboratory experiment, the test results are shown in Table 1. The results of this test are carried out in accordance with variations in the water flow rate of 35 m^3/s, 40 m^3/s, 45 m^3/s and 0 m^3/s, and a runner braking variation to get a turbine rotation of 90 rpm, 70 rpm, 50 rpm, 30 rpm and finally, a maximum braking turbine rotation equal to 0 rpm.

Table 1

Kinetic Turbine Test Results

Q, m^3/h	n, (rpm)	ΔF, (N)	V, (m/s)	T, (Nm)	Water Power	Turbine Power	Eff
35	90	3.2	2.6	0.448	32.8	4.22	12.86
35	70	4.7	2.6	0.658	32.8	4.82	14.69
35	50	6.6	2.6	0.924	32.8	4.84	14.74
35	30	8.5	2.6	1.19	32.8	3.74	11.39
35	0	11.2	2.6	1.568	32.8	0	0
40	90	4	2.86	0.56	45.36	5.28	11.63
40	70	6.1	2.86	0.854	45.36	6.26	13.79
40	50	8.7	2.86	1.218	45.36	6.37	14.05
40	30	10.4	2.86	1.456	45.36	4.57	10.08
40	0	12.8	2.86	1.792	45.36	0	0
45	90	5.8	3.25	0.822	65.896	7.65	11.61
45	70	7.8	3.25	1.092	65.896	8.00	12.14
45	50	9.6	3.25	1.344	65.896	7.03	10.67
45	30	10.9	3.25	1.526	65.896	4.79	7.27
45	0	14.5	3.25	2.03	65.896	0	0
50	90	8.6	3.6	1.204	89.838	11.34	12.62
50	70	11.1	3.6	1.554	89.838	11.38	12.67
50	50	13	3.6	1.82	89.838	9.52	10.6
50	30	16.2	3.6	2.268	89.838	7.12	7.93
50	0	17.3	3.6	2.422	89.838	0	0

From the graph of Fig. 9 it can be seen that the highest average turbine torque is at a water flow rate Q=35 m^3/s and at a maximum turbine runner braking. The second highest turbine torque is when the water flow rate is equal to Q=45 m^3/s. While the lowest turbine torque is at the water flow rate of Q=50 m^3/s and at Q=40 m^3/s.

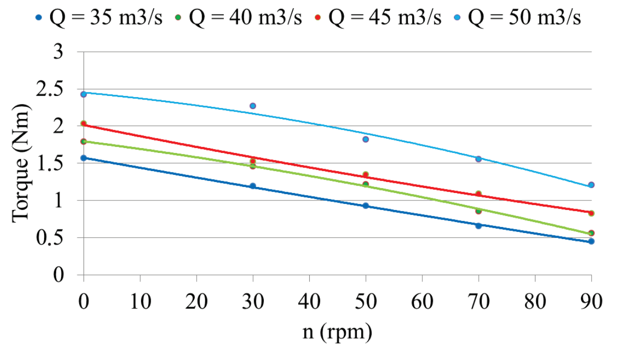

Fig. 9. The relationship between the turbine torque vs turbine rotation graph

From the graph of Fig. 10 it can be seen that the average highest turbine efficiency is at a water flow rate Q=35 m^3/s. The highest turbine efficiency is at Q=35 m^3/s and at a turbine rotation n=60 rpm. The second highest turbine efficiency is at the water flow rate Q=40 m^3/s and at a turbine rotation n=60 rpm. While the lowest efficiency occurs at the time of the water flow rate Q=45 m^3/s and at Q=50 m^3/s.

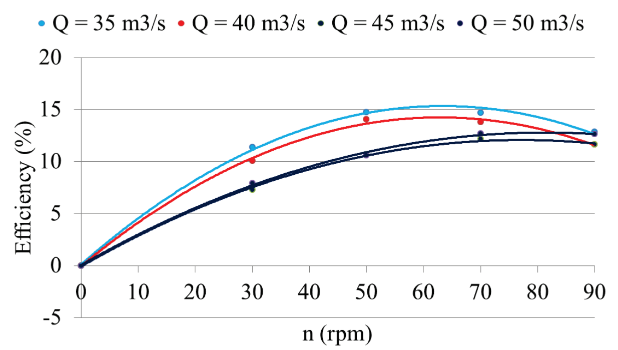

Fig. 10. The relationship between the turbine efficiency vs turbine rotation graph

From the graph in Fig. 11 it appears that the average highest power produced is at the water flow rate Q=50 m^3/s. The highest produced turbine power is at Q=50 m^3/s and at a turbine rotation n=80 rpm. The second highest power turbine is produced at the water flow rate Q=45 m^3/s and at a turbine rotation n=70 rpm. While the lowest turbine power production occurs at the water flow rate of Q=40 m^3/s and at Q=35 m^3/s.

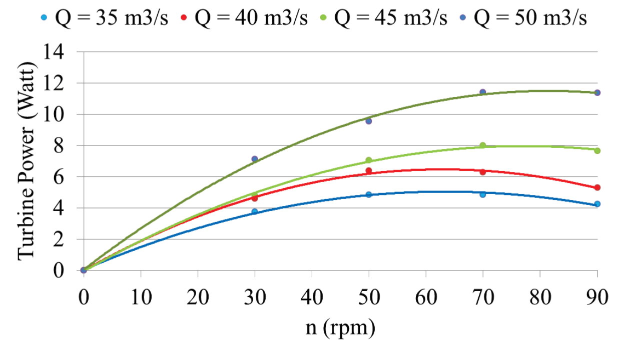

Fig. 11. The relationship between the turbine power vs turbine rotation graph

5. 2. Research results, visualizations of water and turbine blade's movement on a kinetic turbine

As mentioned earlier, the behavior of water movement in the turbine and turbine blade behavior will be recorded in the form of video recordings. Recording this video will then be described as an image sequence for each movement change. The video will be converted into an image for each frame.

Fig. 12 shows an example of some converted images from a video into an image per frame as follows.

From these pictures, every turbine blade and water flow movement could be seen. For the complete observation, some picture was taken for the maximum blade momentum and of course the maximum water movement to get the highest water push or pressure given to the turbine blade. Another picture was also taken to observe the blade and water movement for the worst turbine condition, to find out the lowest water turbine performance. The maximum water turbine performance could be seen from the maximum turbine blade opening and the maximum water flow pushing the turbine blade and converting the water energy to be a mechanical energy.

Fig. 12. Blade and water behavior

6. Discussions on the water flow and turbine blade movement

6. 1. Water flow and turbine blade movement on the first rotor position

To find out what happened in the turbine room, the first frame image of the video recording was taken at the time of observation. Fig. 13 shows the image that will be observed as a blade movement in the first position.

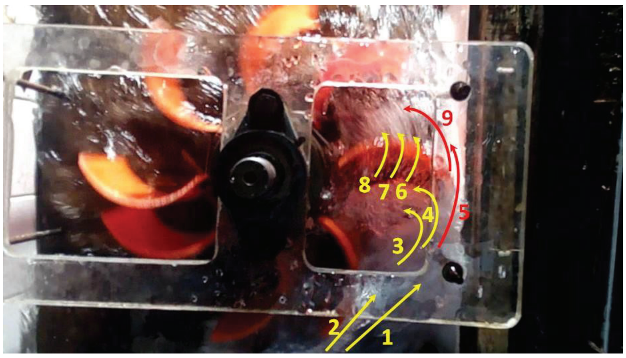

Fig. 13. Turbine blade at the first position

In the first blade movement position it is shown that there are several water flow directions entering the turbine blade (Fig. 13).

Looking at the flowline number 1 and flowline number 2 it is indicated that the initial flow of water is entering the turbine runner. While seeing flowline number 3 and flowline number 4 it is indicated that the water flow enters the blade to push the turbine blade, spinning the turbine rotor and produces mechanical energy. This is based on the momentum theory [14], which says that the momentum of a moving object is defined as the result of mass and velocity. In straight-moving objects, the momentum is also called linear momentum. The law of conservation of momentum reads: «The linear momentum of an object does not change as long as there is no external force acting on the object» [12, 15].

Flowline number 5 is the water flow that does not enter the blade area and immediately leaves the turbine runner without giving any effect to the blade [13]. Flowline number 6–8 indicates that part of the water is flowing over the top of the turbine, so that the water flow does not fully push the turbine blade. The effect of water flow passing through the blade top area will reduce the mechanical energy produced [13].

Furthermore, flowline number 9 shows that some water does not push the blade before entering the next blade chamber, resulting in no additional mechanical energy generated.

6. 2. Water flow and turbine blade movement on the second rotor position

Blade movement at the second position (Fig. 14) is the blade movement after the first movement.

At the second blade movement position, several directions of water flow entering the turbine blade are shown.

From the picture in Fig. 9, it is seen that flowline 1 and flowline 2 indicate the initial flow of water entering the turbine runner. Secondly, flowline 3 is the flow of water that does not enter the blade area and immediately leaves the turbine runner without giving a momentum effect to the blade. Thirdly, flowline 4 indicates that the water flow enters the blade to push the turbine to spin and produce mechanical energy. While, flowline 5 and 6 shows that a vortex developed in the blade chamber. The vortex will produce a mechanical energy provided by the blade. Furthermore, flow lines 7–9 indicate that part of the water flow jumps over the top of the turbine. The effect of the flow of water passing through the top of this blade will reduce the mechanical energy produced.

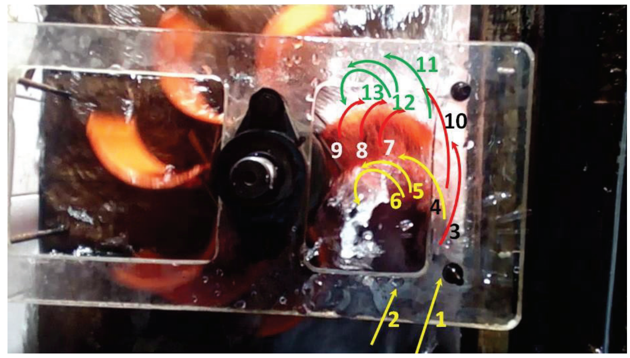

Fig. 14. Turbine blade at the second position

Flowline 10 indicates that some of the water that does not push the previous blade will enter the next blade chamber so that the blade also produces mechanical energy. Flowline 11, 12 and 13 push the next turbine blade and also produce mechanical energy. Finally, in this section there is no indication that there is a flow of water that jumps over the blade.

6. 3. Water flow and turbine blade movement on the third rotor position

Blade movement on the third position (Fig. 15) is the blade movement after the second blade movement.

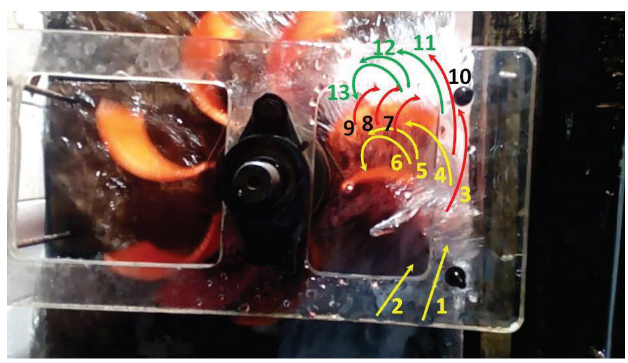

Fig. 15. Turbine blade at the third position

At the third blade movement position, it is shown that several water flows are entering the turbine blade. It could be seen that flowline 1 and flowline 2 indicate that the initial water flow is entering the turbine runner.

Flowline 3 is the flow of water that does not enter the blade area and immediately leaves the turbine runner without giving any effect to the turbine blade. While, flowline 4 indicates that the water flow enters the blade and pushes the turbine blade to spin the turbine and produce mechanical energy.

Flowline 5 and 6 shows that a vortex developed in the blade chamber. The vortex will produce a mechanical energy provided by the blade. Flowline 7–9 indicate that part of the water flow jumps over the top of the turbine. The effect of the flow of water passing through the top of this blade will reduce the mechanical energy produced.

Flowline 10 indicates that some of the water that does not push the previous blade will enter the next blade chamber so that the blade also produces an additional mechanical energy. So the flow line 11, 12 and 13 push the next blade and also produces an additional mechanical energy.

In this section there is no indication that there is a flow of water that jumps over the blade. What is visible is the water that leaves the blade after the water rotates in the blade area, providing mechanical energy, and immediately leaves the blade chamber to the turbine chamber exit.

Observation was also taken to indicate the lowest turbine performance by choosing. Fig. 16 shows the picture of the lowest turbine performance.

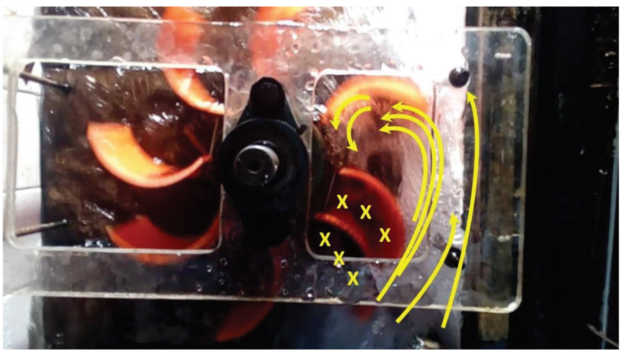

Fig. 16. The lowest turbine performance

In the momentary picture, Fig. 16 shown above, it is seen that there is a blade that has not been filled with water. So that the drive on the turbine as a whole is reduced, because only the blade gets the water flow pressure. The sign(x) shows the space between two blades that are not driven by the water power. While the flow of water denoted by an arrow shows the flow of water that pushes the other blade and there is also a flow of water that does not push the blade but directly leaves the turbine. The turbine blade gets a boost proven by the action in the blade area (rotating arrow). Compared to the images that get two or three blades pushed by the water flow, this picture shows that the weakest turbine drive occurs when only one blade gets a boost. This blade visual observation is the worst water and turbine blade behavior.

7. Conclusions

1. There is an improvement of the kinetic turbine performance, but it is very small. Actually, it is expected that there will be a more significant turbine performance improvement.

2. The maximum power produced is as big as 2,422 Nm which occurs at the time of the water flow rate given is 50 m^3/s and at a maximum braking.

3. The best turbine efficiency is about 12.86 %, which occurs at the 35 m^3/s water flow rate and with a 0.448 Nm torque.

4. The blade closing, when the water jets hit the blade back part, is also a bit too late. As a result, the turbine rotor would get an inverse push and produces an opposite torque. The overall torque would decrease and causes a low turbine performance.

References

1. An Outer Movable Blade Vertical Shaft Kinetic Turbine Performance / Boedi S. D., Soenoko R., Wahyudi S., Choiron M. A. // International Journal of Applied Engineering Research. 2015. Vol. 10, Issue 4. P. 8565–8573.
2. The Influence of Flow Steering Angle on the Performance a of Cup-Bladed Kinetic Turbine / Monintja N. C. V., Soenoko R., Wahyudi S., Irawan Y. S. // International Journal of Applied Engineering Research. 2014. Vol. 9, Issue 20. P. 7481–7489.
3. Dual nozzle cross flow turbine as an electrical power generation / Rantererung C. L. Soeparman S., Soenoko R., Wahyudi S. // ARPN Journal of Engineering and Applied Sciences. 2016. Vol. 11, Issue 1. P. 15–19.
4. Soenoko R., Rispiningtati, Sutikno D. Prototype of a Twin Kinetic Turbine Performance as a Rural Electrical Power Generation // Journal of Basic and Applied Scientific Research. 2011. Vol. 1, Issue 10. P. 1686–1690.
5. Yang B., Lawn C. Fluid dynamic performance of a vertical axis turbine for tidal currents // Renewable Energy. 2011. Vol. 36, Issue 12. P. 3355–3366. doi: https://doi.org/10.1016/j.renene.2011.05.014
6. Yang B., Lawn C. Three-dimensional effects on the performance of a vertical axis tidal turbine // Ocean Engineering. 2013. Vol. 58. P. 1–10. doi: https://doi.org/10.1016/j.oceaneng.2012.09.020
7. Golecha K., Eldho T. I., Prabhu S. V. Investigation on the Performance of a Modified Savonius Water Turbine with Single and Two deflector Plates // The 11th Asian International Conference on Fluid Machinery and Fluid Power Technology,The 3rd Exhibition. Chennai, 2011.
8. Response surface methodology (RSM) application toward the performance of a vertical shaft hinged arc blade kinetic turbine / Lempoy K. A., Soenoko R., Wahyudi S., Choiron M. A. // Journal of Engineering Science and Technology. 2017. Vol. 12, Issue 8. P. 2175–2186.
9. Williamson S. J., Stark B. H., Booker J. D. Performance of a low-head pico-hydro Turgo turbine // Applied Energy. 2013. Vol. 102. P. 1114–1126. doi: https://doi.org/10.1016/j.apenergy.2012.06.029
10. Kailash G., Eldho T. I., Prabhu S. V. Performance Study of Modified Savonius Water Turbine with Two Deflector Plates // International Journal of Rotating Machinery. 2012. Vol. 2012. P. 1–12. doi: https://doi.org/10.1155/2012/679247
11. The Vertical Shaft Kinetic Turbine Optimization using Response Surface Methodology / Monintja N. C. V., Soenok R., Wahyudi S., Suryairawan J. // International Journal of Applied Engineering Research. 2014. Vol. 9, Issue 21. P. 8841–8856.
12. Fluid Mechanics D203. URL: http://www.freestudy.co.uk/fluid%20mechanics/saet1a.pdf
13. Sliasas A., Tullis S. The dynamic flow behaviour of an oar blade in motion using a hydrodynamics-based shell-velocity-coupled model of a rowing stroke // Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology. 2010. Vol. 224, Issue 1. P. 9–24. doi: https://doi.org/10.1243/17543371jset57

14. Wilkinson D. Calculation of Blade-to-Blade Flow in a Turbomachine by Streamline Curvature // Reports and Memoranda No. 3704. 1970. URL: http://naca.central.cranfield.ac.uk/reports/arc/rm/3704.pdf
15. Flow characteristics on the blade channel vortex in the Francis turbine / Guo P. C., Wang Z. N., Luo X. Q., Wang Y. L., Zuo J. L. // IOP Conference Series: Materials Science and Engineering. 2016. Vol. 129. P. 012038. doi: https://doi.org/10.1088/1757-899x/129/1/012038

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DEVELOPMENT OF A RENEWABLE HYBRID POWER PLANT WITH EXTENDED UTILIZATION OF PUMPED STORAGE UNIT EQUIPMENT

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Запропоновано схему гібридної відновлюваної електричної станції з розширеним використанням встановленого обладнання гідроакумулюючого блока для перетворення постійного струму фотоелектричних та вітрових генераторів в змінний.

Схема базується на наявних компонентах з широко використовуваною відпрацьованою технологією. Для видачі потужності та перетворення постійного струму сонячних та вітрових генераторів в змінний окрім мережевих інверторів використовується синхронний генератор гідроакумулюючого блоку. Для обертання генератора крім гідротурбіни також використовується асинхронний двигун, підключений через частотно-регульований привод до загальної шини постійного струму станції. Крім того, до шини постійного струму підключені електрохімічні акумулятори і батареї конденсаторів.

Проаналізовано можливість використання різних типів електричних машин для приводу синхронного генератора і показано перевагу асинхронного двигуна. Змодельовано реакцію асинхронного двигуна на коливання швидкості обертання і показано його здатність брати участь в регулюванні частоти мережі. На прикладі типового добового графіка навантаження і генерації показано, що запропоноване рішення по перетворенню постійного струму в змінний має ККД, близький до ККД мережевого інвертора.

Запропонована схема гібридної станції дозволяє підвищити надійність роботи відновлюваних джерел енергії і стабільність частоти мережі. Це досягається завдяки збільшенню інерції обертових мас в енергосистемі, можливості управління коефіцієнтом потужності синхронного генератора і властивій асинхронному двигуну реакції на коливання швидкості обертання. Створення таких гібридних станцій відкриває шлях до подальшого збільшення частки відновлюваних джерел в енергосистемі

Ключові слова: відновлювана енергетика, гібридна електростанція, частотно-регульований привод, асинхронний двигун

1. Introduction

Electrical power generation is changing dramatically around the world. The installed capacity of wind and solar power plants is already measured in hundreds of GW. Currently, mainly maneuverable gas turbine units and pumped-storage power plants (PSPP) are used to compensate the negative impact of renewable energy (RE) sources on the stability of the power system. In recent years, we can see accelerated growth of different kinds of renewable hybrid power plants (RHPP) which can incorporate photovoltaic systems, wind generators and powerful Li-Ion storage battery units.

This promising technology ensures stable generation of electricity and high maneuverability level of RHPP but it still has a number of drawbacks. On the other hand, more traditional RHPP schemes including those that use small PSPP for energy accumulation are also explored in the world. The true potential of this type of plants has not yet been fully shown; and they can solve the problems that we will encounter as the use of Li-Ion storage batteries in power systems increases.

2. Literature review and problem statement

In power grids, electronically coupled sources have been growing rapidly over the past few years, where the reliability of stable power balance between generation and demand is achieved by the sole use of energy storage [1].