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Numerical Simulation of Multiple Arrays Arrangement of Micro Hydro Power Turbines

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***Abstract*—**River flow over micro hydro power (MHP) turbines of multiple arrays arrangement is simulated with computational fluid dynamics (CFD) software to obtain the flow characteristics. In this paper, CFD software is used to simulate the water flow over MHP turbines as they are placed in a river. Multiple arrays arrangement of MHP turbines lead to generate large amount of power. In this study, a river model is created and simulated in CFD software to obtain the water flow characteristic. The process then continued by simulating different types of arrays arrangement in the river model. A MHP turbine model consists of a turbine outer body and static propeller blade in it. Five types of arrangements are used which are parallel, series, triangular, square and rhombus with different spacing sizes. The velocity profiles on each MHP turbines are identified at the mouth of each turbine bodies. This study is required to obtain the arrangement with increasing spacing sizes that can produce highest power density through the water flow variation.

***Keywords*—**Micro hydro power, CFD, arrays arrangement, spacing sizes, velocity profile, power.

I. Introduction

HYDRO turbines are used to change water pressure from river flow into mechanical or kinetic energy, which can generate electricity [1]. According to [2], MHP technology is needed to generate electricity to residential areas. Besides, MHP is one of renewable energy resources in the world. According to [1], small hydro or MHP is the most economical technology to generate power. This is because MHP use the water flow in a river to generate power, where it is a continuous process. Besides, the costs for manufacture and install MHP turbines are cheaper compared to the tidal and wind turbines.

Most of the computational researches on arrays arrangement are done for tidal turbines, which is almost similar to MHP turbines. Computational Fluid Dynamics (CFD) models are used to analyze the wake effects in arrays of tidal turbines [3]. The simulations of the turbines are done to obtain the wake characteristics of actuator disc and compare with experimental data. According to [4], fluent software is used to simulate 3-D models of Tidal Energy Converter (TEC) turbines with three-row array. In this research, the TEC array arrangement and spacing simulated to identify the performance variation.

Besides that, adaptive mesh method with Gerris solver is used to optimize multiple arrays of tidal turbines in a channel [5]. Reynolds-averaged Navier Stokes (RANS) equations are used with the turbines to stand for frozen rotor. Static blade method is similar with the frozen rotor method. The frozen rotor method is used in the computational domain to consider effect of velocity on it [6]. The CFD software is used here to consider the best arrangement of ocean current turbines, which generate maximum power.

Moreover, Large-eddy Scale (LES) is type of CFD, where the larger turbulent scales are resolved [7]. This method is carried out by creating a framework to generate inflow tidal turbulence data. With the framework, the wake characteristics and power generated have been considered. According to [8], Horizontal-axis Tidal Current Turbines (HATTs) are simulated with RANS CFD method to characterize the performance.

The objectives of this study are to develop a numerical model of river domain over a MHP turbine and obtain the flow characteristics of river flow when subjected with multiple arrays of MHP turbines. First, a numerical model of a river flow has been created to obtain flow characteristics without obstruction in it. Next, MHP turbine bodies with static blades are placed in the river domain with variation of arrays arrangements. Finally, the velocity profiles of each array are determined to identify the changes in the velocities.

II. Kinetic Energy Equation

Kinetic energy (*KE*) is an energy formed as a result from the motion of a medium of fluid or air. The *KE* equation represents the relationship between velocity, mass and kinetic energy. The general equation of *KE* is:

$$KE = \frac{m.v^2}{2} \tag{1}$$

where *KE* is kinetic energy (J): *m* is mass (kg) and *v* is velocity of a fluid flow (m/s).

Meanwhile, for *KE* per unit mass, the formula is presented as following:

$$\frac{KE}{m} = \frac{v^2}{2} \tag{2}$$

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The *KE* can be converted into mechanical energy. The kinetic energy from the water flow can be converted into kinetic energy of rotating shaft (*KE*) by rotating the turbine blade. The formula below proves that velocity is directly proportional to the angular velocity as the kinetic energy is converted into mechanical energy:

$$v = r\omega \tag{3}$$

where r is the radius of turbine shaft andω is an angular velocity

Substitute (3) into (1)

$$KE = \frac{m.r^2.\omega^2}{2} \tag{4}$$

$$KE = \frac{\omega^2}{2} \tag{5}$$

From (5), it is proven that the angular velocity of the rotating turbine blade increases when the kinetic energy increases. Furthermore, the power of the rotating turbine blade calculated with the following equation:

$$P = \omega M \tag{6}$$

whereω is the angular velocity and M is the momentum of torque.

These equations prove that the angular velocity of the turbine blade shaft increases when the velocity of the fluid flow increases. This is because the kinetic energy of the fluid flow is equals to the rotational kinetic energy. Hence, the more kinetic energy is converted into rotational kinetic energy in a turbine, the more power will be generated.

III. Turbine Body and Blade Design

The dimension of the existing MHP turbine blade obtained in Table I is 312mm diameter. The turbine body is designed in computer aided design software as shown in Figs. 1 and 2:

- Diameter (hollow part): 350mm
- Outer diameter: 430mm
- Thickness: 40mm
- Length: 400mm

A blade with diameter of 312 mm and thickness of 70 mm is designed, and assembled with the turbine body.

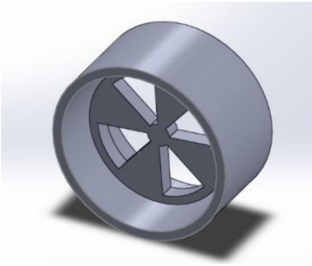

Fig. 1 The designed turbine body and static blade

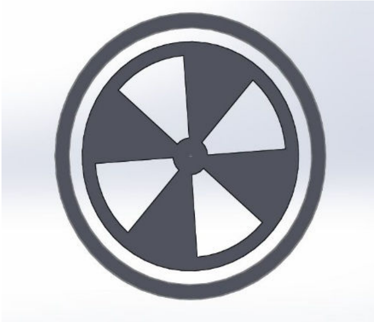

Fig. 2 The blade must be smaller than the turbine body

IV. Model Description

A. Computational Domain

The river domain or the water flow domain is made up of box enclosure. The MHP turbine models are placed in the domain with chosen array arrangements and spacing lengths.

The height of the enclosure box is 4m from the base (Y-axis). The width is 5.5m (X-axis) and the length is 10m (Z-axis). However, this dimension is different according to the spacing lengths between the turbines. There are 4 MHP turbines for each array arrangements.

B. Meshing

The model mesh size used is fine for every array (see Table I). However, the total number of model elements is different according to the number of turbines and spacing lengths between the turbines.

C. Boundary Conditions

For this study, the river flow is standardized to steady fluid flow. The fluid is consists of air at the top and water below since it is an open-channel flow

Inlet: Velocity with upstream height
Outlet: Constant static pressure
Surface: Zero pressure
Bottom: No slip wall
Sidewall: No slip wall

The inlet velocity is 2.5m/s with upstream and downstream heights of 1m. The upstream height is the height of water level of the river at the inlet. The downstream height is the height of the river water level at the outlet.

TABLE I
MESH SIZES FOR DIFFERENT ARRAY ARRANGEMENT

Array arrangement	Configuration	Number of grid elements	Number of nodes
	0%	161,483	29,221
	50%	530,409	104,345
Parallel	100%	671,429	129,351
	150%	677,227	130,189
	200%	675,108	129,849
	0%	2.453,271	510,762
	50%	582,214	113,557
Series	100%	647,487	124,616
	150%	639,472	122,783
	200%	650,892	124,732
	0%	417,182	78,079
	50%	459,336	84,839
Triangular	100%	549,988	98,542
	150%	483,492	89,133
	200%	671,775	129,595
	0%	117,052	21,557
	50%	543,204	106,804
Square	100%	646,506	124,906
	150%	656,557	126,304
	200%	663,951	127,222
Rhombus	0%	602,708	117,588
	50%	664,226	127,868
	100%	683,481	131,211
	150%	664,979	127,921
	200%	671,396	129,098

V. MODEL CONFIGURATION

In each array arrangement, four MHP turbines are placed in the river domain. There are five types of array arrangements are used which are:

1. Parallel arrangement (Fig. 3)
2. Series arrangement (Fig. 4)
3. Triangular arrangement (Fig. 5)
4. Square arrangement (Fig. 6)
5. Rhombus arrangement (Fig. 7)

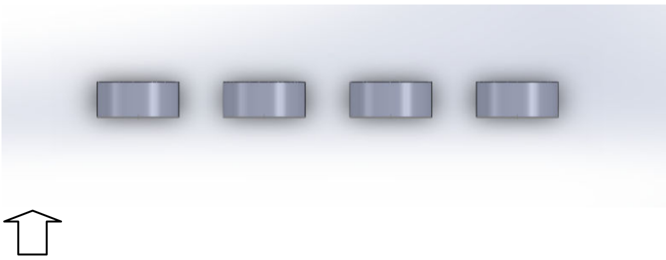

Fig. 3 Parallel arrangement

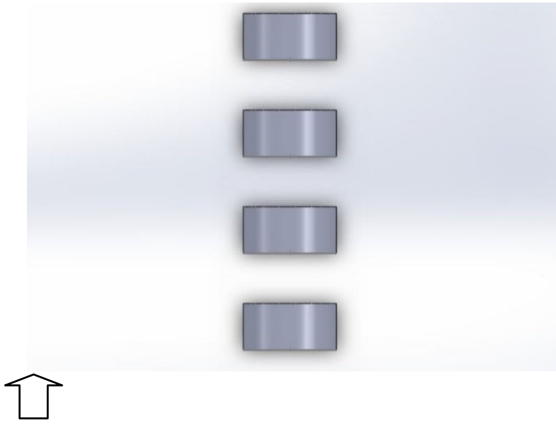

Fig. 4 Series arrangement

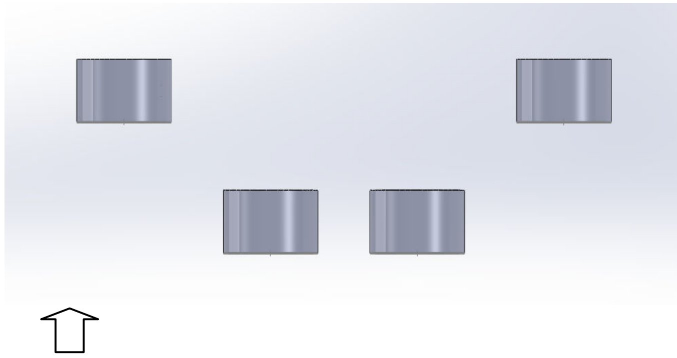

Fig. 5 Triangular arrangement

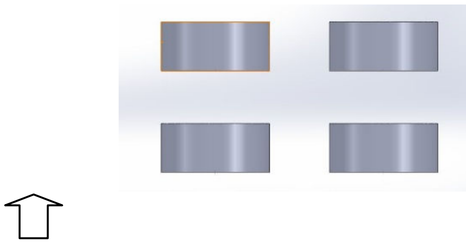

Fig. 6 Square arrangement

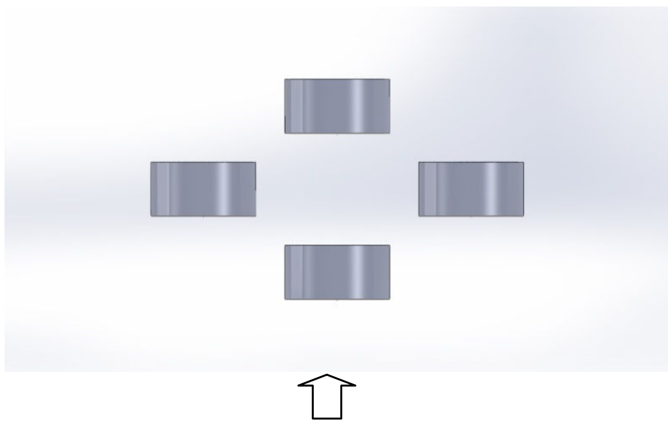

Fig. 7 Rhombus arrangement

The spacing sizes are calculated with respect to the turbine body diameter.

1. 0% diameter: 0mm spacing
2. 50% diameter: 215mm spacing
3. 100% of diameter: 430mm spacing
4. 150% of diameter: 645mm spacing
5. 200% of diameter: 860mm spacing

The first spacing size is 0mm between all the turbines, which the turbines, which the turbines are attached to each other side by side in each arrangement. The arrangements and spacing are done in Solid works 2012 software. The simulation is carried out for all the arrangements with calculated spacing sizes.

VI. Results and Discussion

The CFD simulations and analysis were conducted to study the river water flow through MHP turbines of different types of array arrangements and specified spacing distances between the turbines. These simulations were conducted for two stages. A comparison data is conducted to present the differences of velocities in each turbine in every arrangement. These simulations were carried out with 1 velocity, and 5 different array arrangements with 5 different spacing sizes for each arrangement.

For velocity profile plot, velocity values at the entrance of the turbine were extracted from the line drawn across in front of the turbines. The profiles were plotted for all array arrangements. The velocity values at the turbine mouth must be closer the mean value of the river velocity, which is 2.5m/s. The average velocities for each array arrangement are calculated to determine the best one to generate maximum power.

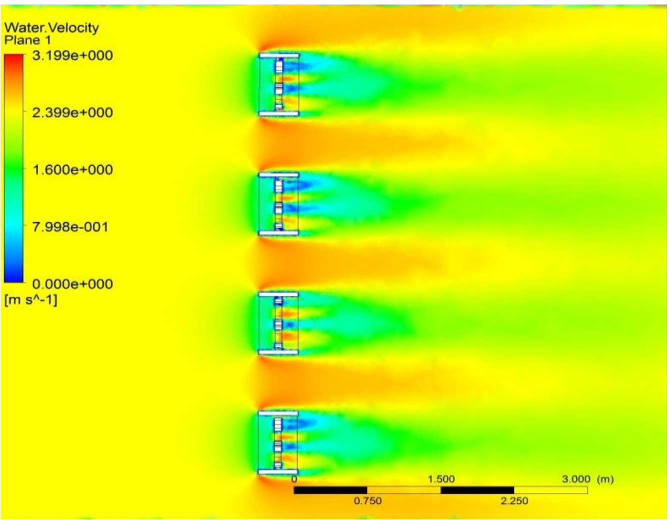

Fig. 8 The effect of velocity flow in MHP turbine with parallel arrangement at 645mm spacing size

Fig. 8 shows the color changes represent the variations of velocities of river flow throughout the MHP turbine body. The velocity decreases as the flow pass through the MHP turbine. However, the velocity changes are consistent in every spacing size for parallel arrangement.

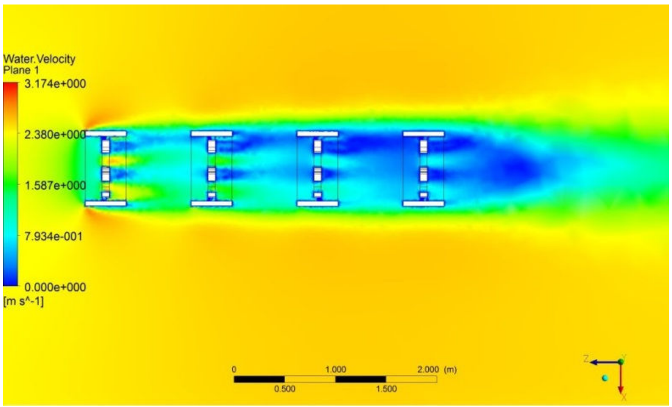

Fig. 9 The effect of velocity flow in MHP turbine with series arrangement at 645mm spacing size

Fig. 9 shows the effect on variations of the velocities in river flow throughout the MHP turbine body. The large drop of velocity occurs as the water pass through the MHP turbines. The water flow almost becomes stagnant. The same flow condition occurs in the other spacing sizes.

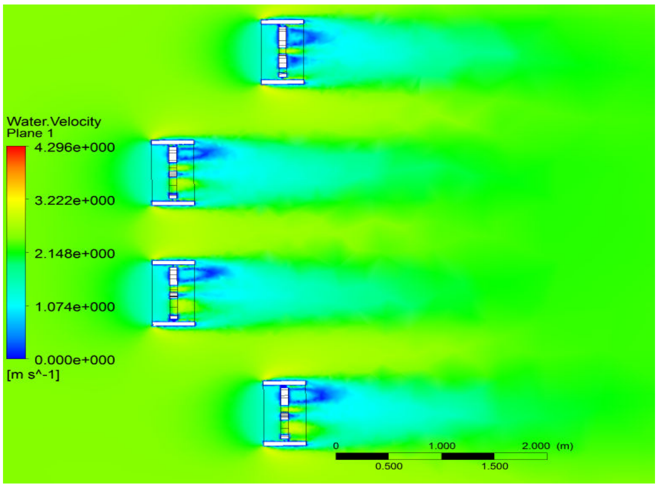

Fig. 10 The effect of velocity flow in MHP turbine with triangular arrangement at 645mm spacing size

Fig. 10 shows the effect of velocities in river flow throughout the MHP turbine body. The flow shows the decrement in velocity as it pass through the MHP turbines. Besides, as the spacing sizes increase, the average velocities increase except for 0mm spacing size, which shows the highest average velocity.

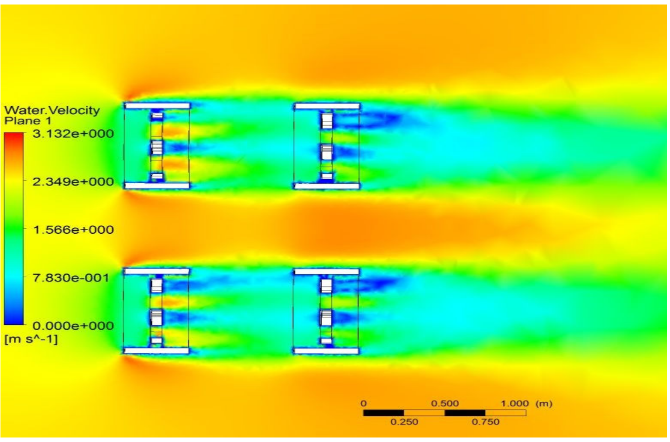

Fig. 11 The effect of velocity flow in MHP turbine with square arrangement at 645mm spacing size arrangement

Fig. 11 shows velocity contours in river flow throughout square arrangements of MHP turbine body. The upstream flow has been truncated by the downstream turbine and the velocity continuously dropped as the flow pass through the MHP turbines. Besides, as the spacing sizes increase, the average velocities increase.

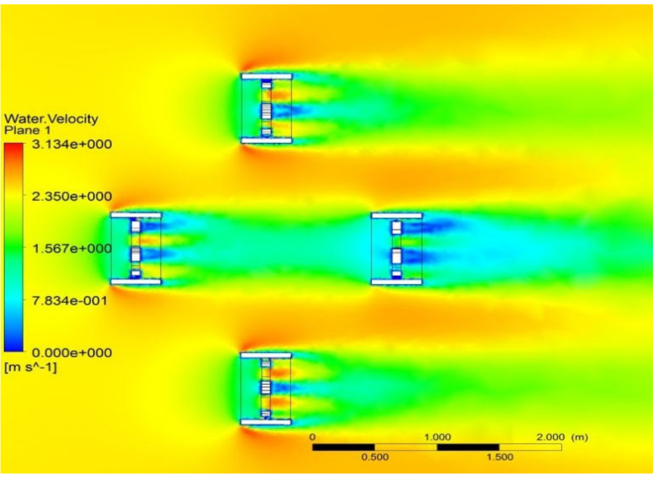

Fig. 12 The effect of velocity flow in MHP turbine with rhombus arrangement at 645mm spacing size arrangement

As shown in Fig. 12, the highest average velocity reached at 0mm spacing size which later it decreases as the flow pass through the rhombus arrangement of MHP turbines. As the spacing sizes increase, the average velocities of the flow increase gradually.

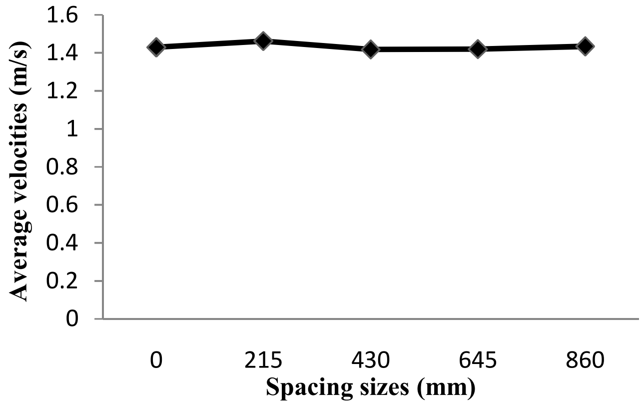

Fig. 13 The effect in average velocities when spacing sizes were increased for parallel array arrangement

Fig. 13 shows the effect of average velocities as the spacing sizes between the MHP turbines in parallel array arrangements were increased. The average values of the velocity at the mouth of the turbine bodies for all the parallel array arrangement were almost equal in every spacing size. Hence, the parallel arrangement is not significant enough to generate energy.

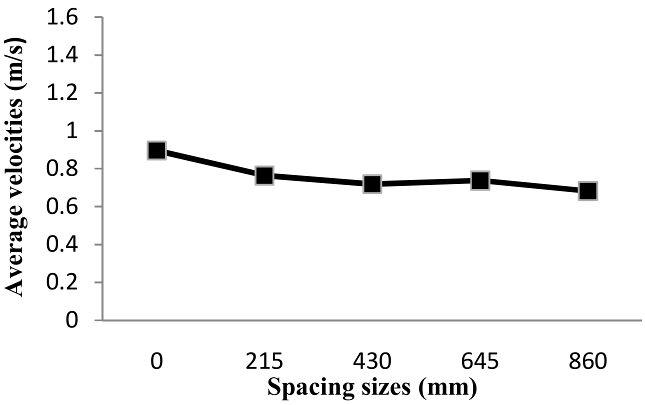

Fig. 14 The changes in average velocities when spacing sizes were increased for series array arrangement

Fig. 14 shows the effect of average velocities as the spacing sizes between the MHP turbines in series array arrangement were increased. The average velocities of the series array arrangement decrease when the spacing sizes increase. Besides, the values of the velocities almost reach 0 m/s as the water flow from Turbine 1 to Turbine 4. This shows that the water flow become stagnant inside the turbine bodies. Hence, this series arrangement is not significant enough to generate energy.

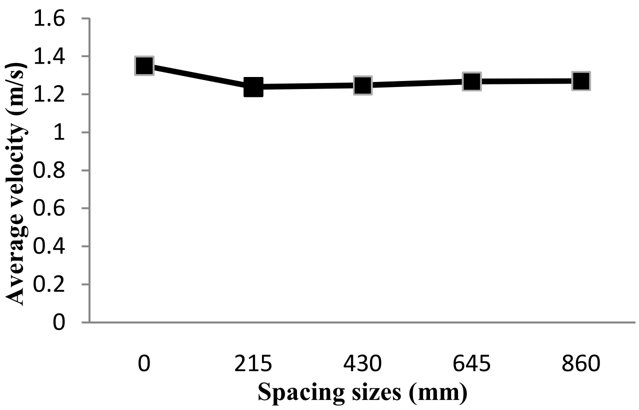

Fig. 15 The changes in average velocities when spacing sizes were increased for triangular array arrangement

Fig. 15 shows the effect of average velocities as the spacing sizes between the MHP turbines in triangular array arrangements were increased. For 0 mm spacing size, the average velocity was the highest compared to other spacing sizes. This proves that when MHP turbines are close to each other, the kinetic energy from the water flow can generate more energy. However, at 215mm, the average velocity decreases compared to 0mm. Then, the average velocities increases from 215mm until 860mm spacing sizes. Hence, this triangular arrangement is significant to generate energy.

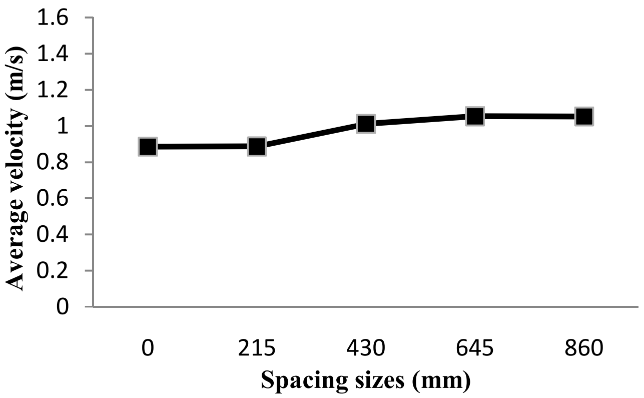

Fig. 16 The changes in average velocities when spacing sizes were increased for square array arrangement

Fig. 16 shows the effect of average velocities as the spacing sizes between the MHP turbines in square array arrangements were increased. The average velocities increase when the spacing sizes increase at the spacing sizes of 215 mm until 860mm. However, the average velocity does not have much change from 0mm until 215mm spacing sizes. Hence, this square arrangement is significant to generate energy because average velocity increases as the spacing sizes increased.

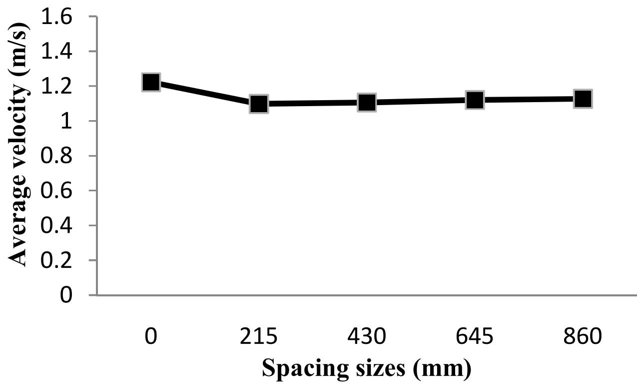

Fig. 17 The changes in average velocities when spacing sizes were increased for rhombus array arrangement

Fig. 17 shows the effect of average velocities as the spacing sizes between the MHP turbines in rhombus array arrangements were increased. For 0mm spacing size, the average velocity was the highest compared to other spacing sizes. This proves that when MHP turbines are close to each other, the kinetic energy from the water flow can generate more energy. However, the average velocity at 215mm was the lowest. From 215mm until 860mm spacing sizes, the average velocities of the rhombus array arrangement increases. Hence, this rhombus arrangement is significant to generate energy.

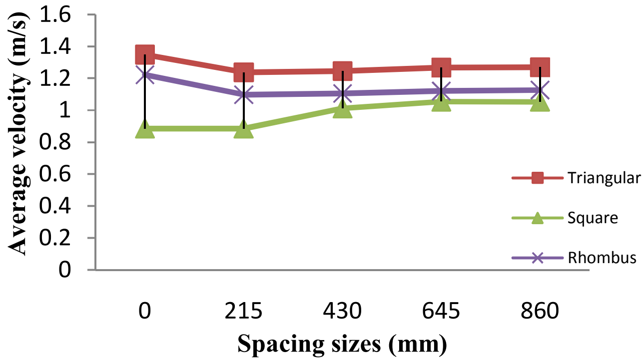

Fig. 18 The comparison of average velocities when spacing size increases between triangular, square and rhombus arrays arrangements

From Fig. 18, triangular, square and rhombus array arrangements of MHP turbines were compared since they were significant to generate energy from the river water flow according to the results above. As the spacing sizes increase, the average velocities at the mouth of the MHP turbines increases except for certain spacing sizes. At 0 mm spacing size for the entire array arrangements, the average velocity was the highest for triangular and rhombus arrays arrangements. The average velocities of triangular arrangement were the highest compared with rhombus and square arrangements. This shows that triangular arrangement is more significant to generate energy from kinetic energy of the water flow; however, the rhombus and square arrangements are still applicable to generate energy.

VII. Conclusions

From the study by using the array arrangements, it was proven that triangular, square and rhombus array arrangements as the significant arrangements to generate power, and the triangular arrangement was the best since the average velocity through the MHP turbines was the highest. The power was generated by extracting kinetic energy from multiple MHP from free-flowing stream of the water. However, the parallel and series array arrangements were not significant to generate power. The parallel array arrangement does not show significant changes in average velocities as the spacing sizes increases, meanwhile, the water flow series array arrangement almost become stagnant. Hence, the triangular, square and rhombus arrangements were significant to generate power but parallel and series arrangements were not significant.

However, since the application of MHP is in rivers the spacing between turbine bodies must be limited so as it would not be the source of obstruction to transports and other uses. Each river geographical properties must be analyzed for the most optimum spacing to harvest highest electrical energy and at the same time allowing various river activities to continue as normal.

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