CFD analyses of a tidal hydro-turbine (THT) for utilising in sea water desalination

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Abstract— This work presents a modified concept of a tidal hydro-turbine (THT) used in desalination of sea water. THT can be used for the entire desalination process to derive energy from the intake of feed water, pre-treatment and producing required pressure for the system. The turbines extract energy from the tidal movement and run the water pump in order to provide the hydraulic pressure of the desalination unit. The performance of the turbine was assessed and its graphs were plotted using Computational Fluid Dynamics (CFD) modelling. Index terms: Tidal hydro-turbine, CFD, desalination, ANSYS FLUENT, Wave power.

I. INTRODUCTION

Freshwater is at the heart of sustainable development and is vital for socio-economic development, energy, and food production, healthy ecosystems and for human survival itself. By 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity [1]. The promising point is that there is a significant amount of water in our planet and which is near 70% of the Earth's surface [2]. One of the best solutions for the world's water crisis is desalination [3]. Desalination is a water treatment process that removes salts from saline water to produce freshwater. The biggest weakness of seawater desalination is that its process requires a significant amount of energy. Renewable energy can be utilised to power desalination devices. Ocean-energy provides a renewable resource with the advantage of being predictable many days in advance, the stable duration the day and night, and significantly greater in its energy density compared to wind and solar energies. Furthermore, the world’s potential wave-power resource is estimated to be approximately 2.11 TW to 95% confidence, and the theoretical values of each zones of the earth are illustrated in fig. 1 [4].

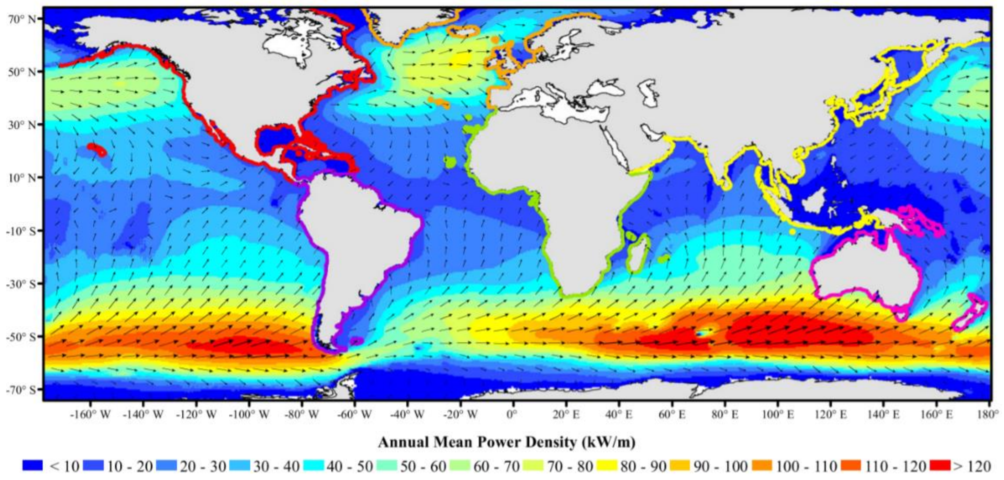


Fig.1 - Annual mean wave power density (colour) and annual mean best direction (→) [4].

Although the advantages of energy generated from the ocean for powering desalination processes is appealing, the potential of ocean power for desalination systems has not been researched in detail. One of the ocean device candidate which can be used throughout the entire desalination process to operate for the intake of feed water, pre-treatment, and producing electricity requirement of the system is tidal hydro-turbine (THT). THT systems have been widely utilised in ocean industries [5] but their usages for the desalination have not studied yet. In this work, a new concept for seawater desalination is introduced and the main part of the system which is turbine was simulated computationally in order to analyse the functionality and performance of such systems for ocean power desalination.

II. MODEL DEVELOPMENT: THE TIDAL HYDRO-TURBINE DESALINATION CONCEPT

The tydal hydro turbione (THT) provides required pressure for desalinating the salt water into fresh water by the use of membrane based technqiues such as Reverse Osmosis. Functionality and performance of such techniques extremly depend on providing a minimum amount of energy necessary for the conversion. That is why 65% of the existing desalination power plants around the world are directly or indirectly using RO based systems [6]. Table 1, shows the most of exist technologies for water desalination and their energy consumption [7].

Table 1 - energy consumption of water desalination [7]

Technology	Concept	Mean energy consumption for unit cubic meters
Reverse Osmosis (RO)	Membrane Filtration	2-4 kWh
Electrodialysis (ED)	Electrochemical and Membrane Filtration	4-8 kWh
Multi stage flash distillation	Evaporation	10-16 kWh
Multi effect distillation	Evaporation	6-9 kWh
Thermal Vapor Compression	Evaporation	6-12 kWh

RO is based on the diffusion of water through a membrane (Fig. 2) [8]. The membrane's features determine its ability to allow water to be transported preferentially over the solvent. A difference in pressure is needed between the feed and the permeate sides of the membrane to ensure water flow through the RO membrane, which must be significantly higher than the osmotic pressure. According to previous works, operating pressure of RO should be about 50-60 bar [9], nevertheless, some professional RO companies are developing new materials and technologies which can be used with far less than this amount of pressure [10].

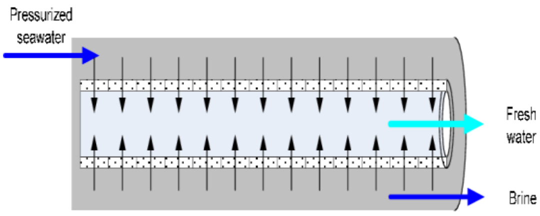


Fig. 2 - Water traveling through an RO membrane

[8]. Tidal hydro-turbine can be used for the entire desalination process to derive energy from the intake of feed water, pre-treatment and producing pressure requirement of the system (See Fig. 3). The turbines extract energy from the tidal movement and run the water pump in order to provide the hydraulic pressure needs for the desalination unit. The number of turbines depends on their size and required pressure of the desalination unit and also the offshore conditions.

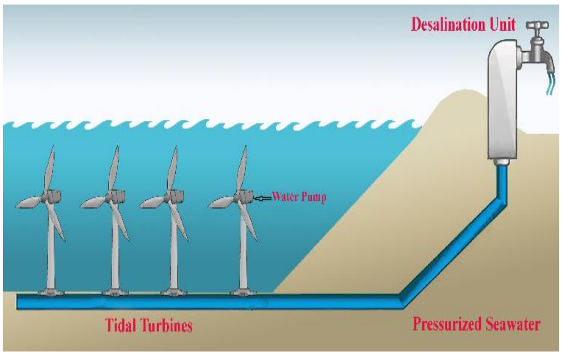


Fig. 3 - The tidal hydro-turbine (THT) desalination concept

III. CFD ANALYSES RESULTS THE SYSTEM IN OPERATION

Table 2 - turbine geometrical and stream specifications	
Height of Blade	0.3 m
Velocity of water	1 m/s
Number of Blades	3
Diameter of hub	0.1 m
Velocity of water	1 m/s

In Table 2 the turbine geometrical and stream specifications are listed. These parameters were selected in order to understand with ordinary blade how much pressure one turbine can provide for desalination system. It was assumed that the water velocity is 1.0 m/s. It is obvious that the results of standard blades will be proper.

Interaction between tidal turbines and ocean waves are mathematically complex [11] and different parameters are required for their complete description. To analye the main characteristics and performance of the turbine, transient time-accurate and dynamic mesh 3D CFD model was applied with the academic version of ANSYS FLUENT 19 program.

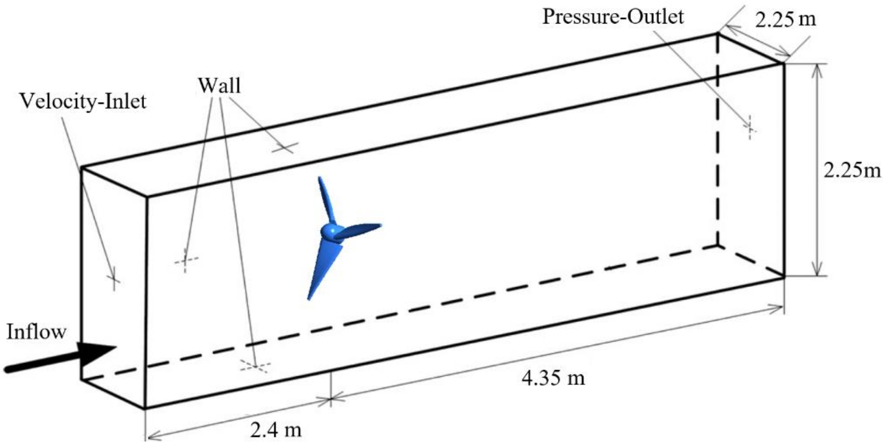


Fig. 4 - Computational domain and boundary conditions of the turbine in operation

3D simulations are carried out with the aim of an accurate investigation of the differences in the complex aerodynamic flow associated with the straight and the hydro turbines [12]. Pressure and velocity contours are then plotted for different time intervals (see Figs 5 and 6) to illustrate how the systems works in operation under different conditions was then modeled into a rectangular shape based on literature[13]. The external domain is a rectangular with the size of 2.25 m x 4.75 m x 2.5 m and the internal rotation area is a cylinder of diameter of 0.75 m and height of 0.3 m. Fig. 4 shows the internal domain where a turbine rotates, the external domain where the fluid flows and the boundary condition. If in a rotational cycle the torque (T_n) is recorded n times, the mean torque is measured as follows:

$$T_m = \frac{1}{n}\sum_{i=1}^{n} T_i \qquad (1)$$

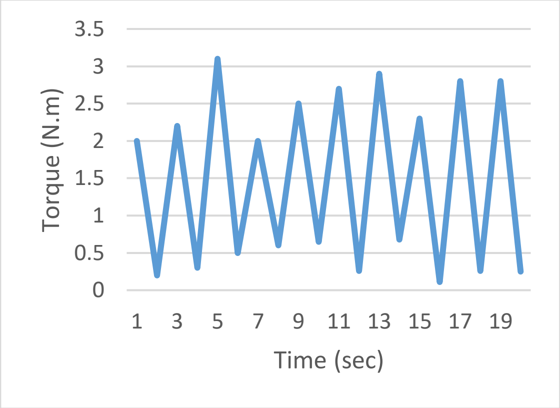
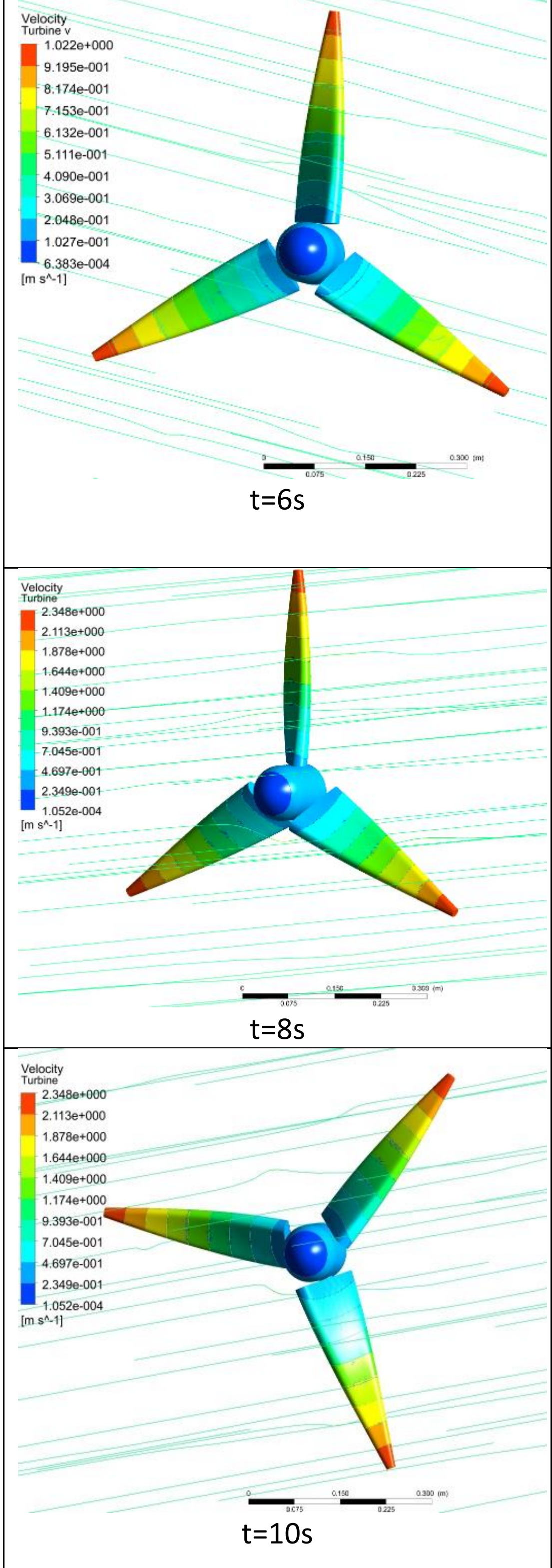


Fig. 7 – Torque of all blades in deferent times

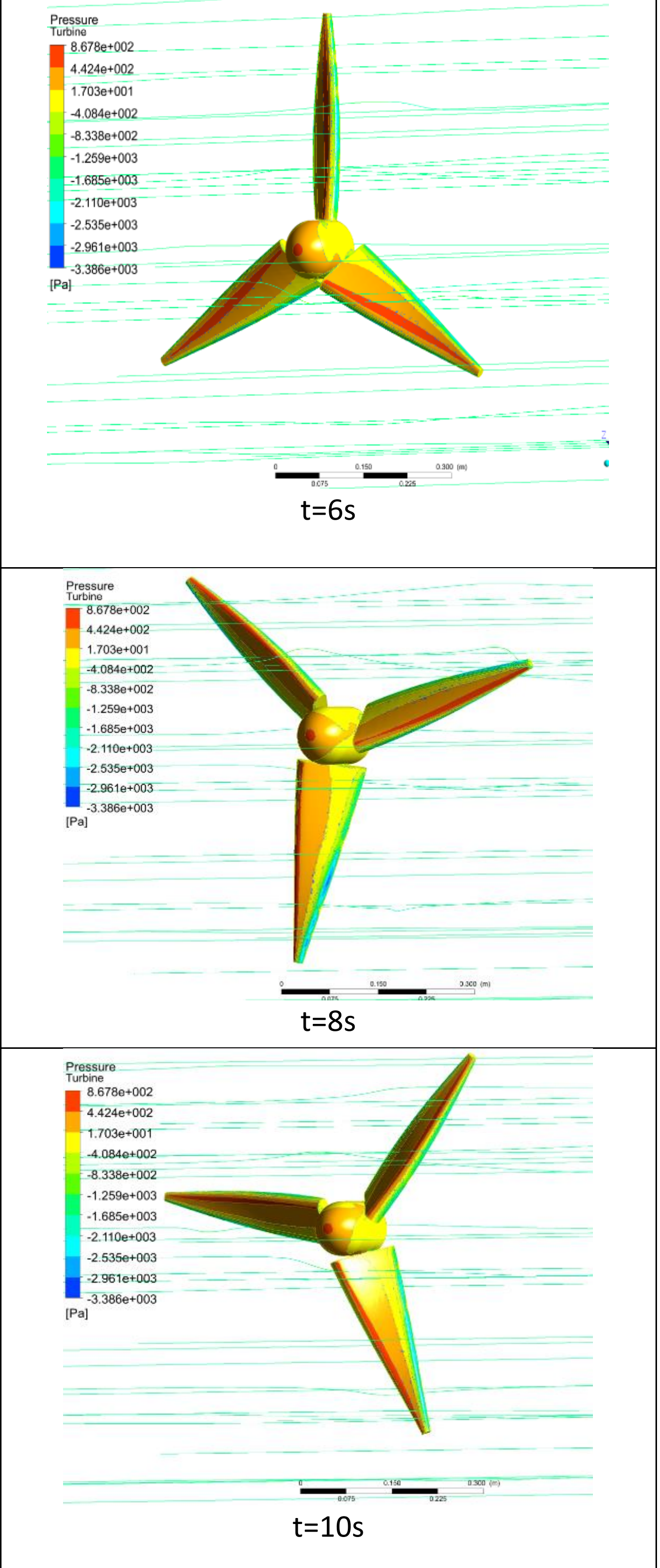


t=6s

t=8s

t=10s

Fig. 5 – Radial velocity ANSYS FLUENT 19 (3d, dp, pbns, rngke, dynamesh, transient)



t=6s

t=8s

t=10s

Fig. 6 - Pressure distributions ANSYS FLUENT 19 (3d, dp, pbns, rngke, dynamesh, transient)

The mean torque is calculated as 1.45 N.m. And then the power (P) generated by the turbine is obtained by using the mean torque and angular velocity (ω) of rotation (Eq. 2) [14].

$$P=T_m \omega \tag{2}$$

Radial velocity contour of the turbine is nshown in the Fig. 8. By btaiobtaining mean radial velocity and Eq. 2 the power calculated as 5.8 J.

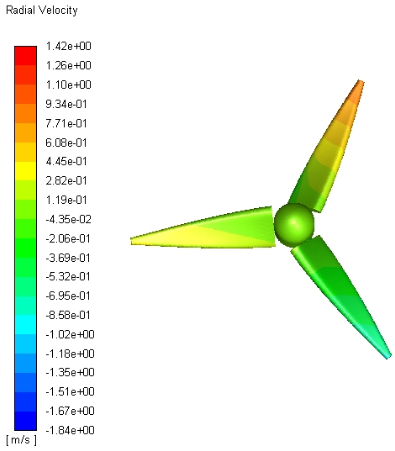


Fig. 8 – Radial velocity contour of the turbine (m/s)

CONCLUSION

In this current study, a new concept of using hydro-turbine for providing a pressure of the RO system was developed and the main part of the system by 3D CFD model in ANSYS FLUENT was simulated. The amount of obtained power turbine can be a proper indicator for designing of a edesalination plant. Since each RO system because of the amount of salinity and technology used needs a ispecific amount of pressure, this indicator can be used in order to determine the number of required turbines and its size as well.

REFERENCES

1. Eliasson, J., *The rising pressure of global water shortages.* Nature News, 2015. **517**(7532): p. 6.
2. Donchyts, G., et al., *Earth's surface water change over the past 30 years.* Nature Climate Change, 2016. **6**(9): p. 810.
3. Bindra, S. and W. Abosh, *Recent developments in water desalination.* Desalination, 2001. **136**(1-3): p. 49-56.
4. Gunn, K. and C. Stock-Williams, *Quantifying the global wave power resource.* Renewable Energy, 2012. **44**: p. 296-304.
5. Khan, N., et al., *Review of ocean tidal, wave and thermal energy technologies.* Renewable and Sustainable Energy Reviews, 2017. **72**: p. 590-604.
6. Wangnick, K., *International Desalination Association IDA*. 2004, Worldwide Desalting Plants Inventory Report.
7. Li, Z., et al., *Towards sustainability in water-energy nexus: Ocean energy for seawater desalination.* Renewable and Sustainable Energy Reviews, 2018. **82**: p. 3833-3847.
8. Serna, Á. and F. Tadeo, *Offshore desalination using wave energy.* Advances in Mechanical Engineering, 2013. **5**: p. 539857.
9. Wilf, M. and L. Awerbuch, *The guidebook to membrane desalination technology: reverse osmosis, nanofiltration and hybrid systems: process, design, applications and economics*. 2007: Balaban Desalination Publications.
10. Qi, S., et al., *Aquaporin-based biomimetic reverse osmosis membranes: Stability and long term performance.* Journal of Membrane Science, 2016. **508**: p. 94-103.
11. Falnes, J., *Ocean waves and oscillating systems: linear interactions including wave-energy extraction*. 2002: Cambridge university press.
12. Alaimo, A., et al., *3D CFD analysis of a vertical axis wind turbine.* Energies, 2015. **8**(4): p. 3013-3033.
13. Marsh, P., et al., *Three-dimensional numerical simulations of straight-bladed vertical axis tidal turbines investigating power output, torque ripple and mounting forces.* Renewable Energy, 2015. **83**: p. 67-77.
14. Nabavi, Y., *Numerical study of the duct shape effect on the performance of a ducted vertical axis tidal turbine*. 2008, University of British Columbia.