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RESOURCE ASSESSMENT OF THE AGULHAS CURRENT FOR THE PURPOSE OF MARINE ENERGY EXTRACTION

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ABSTRACT

The Agulhas current holds a large amount of untapped energy which has the potential to be harnessed through the use of suitable ocean turbines. This current is investigated in respect to the current velocity and current direction variability through analysing statistical properties of measured *in situ* time series data. The focus area lies between the coast of Port Edward (-31.077, 30.285) and Port Elizabeth (-34.07, 25.67). The available data highlighted a site just off Cape Morgan (-32.507, 28.831) as the highest energy yield location for an ocean current turbine plant installation. The site is characterised by an average velocity of 1.5 m/s and has reasonable access to the national power grid. The Agulhas current has some unique behaviour traits, namely the erratic presence of the Natal Pulses. These large cyclonic meanders can have a diameter of up to 150 km and persist for approximately 40 days in one area potentially affecting turbine energy production. In order to determine the resource that can practically be extracted, a numerical turbine model, based on existing tidal turbines, is used and a capacity factor of 51% was found for the Cape Morgan site.

Keyword: Agulhas Current, marine energy extraction, resource assessment, Natal Pulses

1. INTRODUCTION

The purpose of this paper is to interrogate the available data on ocean current energy resources around South Africa (SA) which ultimately may be utilised for the generation of electricity. Flanking the SA coastline are two predominant currents: the warm Agulhas Current with a Western boundary and the cold Benguela Current with an Eastern boundary. The Agulhas Current flows towards the South Pole and the Benguela towards the Equator. It has been found that the Benguela Current has mean flow speeds which range from 0.11 m/s to 0.23 m/s and transports between 15 and 20 Sv (Gyory, et al., 2012). These values indicate that the Benguela current flows too slowly to drive marine turbines. The Agulhas Current has been found to have approximate transport values of 70 Sv (Bryden, et al., 2005) and thus is further investigated.

2. BACKGROUND

The bathymetry of the South African coastline makes extracting energy from the Agulhas Current attractive as the continental shelf narrows between Maputo (-25.965, 32.589) and Port Elizabeth (-33.967, 25.583) causing the current to flow near the shore with a high velocity. The narrow shelf with a steep continental slope and uncomplicated topography helps stabilise the Agulhas Current in this region. There is one area of exception – The Natal Bight (-29.850, 31.017), situated between Durban and Richards Bay. This area has a wider continental shelf and the shelf's morphology change destabilises the Agulhas Current, resulting in infrequent formation of Natal Pulses (Lutjeharms, 2006). These meanders travel down the coastline and can affect the performance of energy extraction technology deployed.

Natal Pulses are large solitary meanders in the Agulhas Current associated with a cold-water core and a cyclonic circulation inshore of the current (Rouault, 2011). The pulses grow steadily in diameter as they move south-westward along the continental slope, with a typical diameter of 150 km which displaces the current's core seaward. This results in a sharp decrease in velocity of the current close to the coast and the direction of the current possibly reversing as the pulse passes over a specific point. The presence of a pulse can persist between 50 to 240 days and has mean frequency of occurrence of 1.6 times a year in the Southern Agulhas region (Rouault, 2011). The Agulhas undercurrent is only seen in waters deeper than 800 m (Beal, 2003) which falls outside the region of turbine deployment. These oceanographic findings are taken into consideration when examining the potential for resource extraction.

3. METHODOLOGY

The resource assessment was undertaken to determine the technical feasibility of installing marine turbines in the path of the Agulhas Current for power extraction. The economic feasibility of deploying turbine in the Agulhas Current is not considered in this assessment. Owing to present technology constraints, the assessment is constrained to areas with suitable mooring depth and available data. The data that was used for the assessment is the data available in the public domain supplied by Eskom.

3.1. Factors considered during assessment:

Technology specific factors:

- *Operational depth*: the operational depth of the technology is important to consider for this will limit the number of available sites that can be considered.
- *Generator Operating Range:* determines the practically extractable power.
- *Array configuration and spacing:* wake regions can affect extractable power downstream.
- *Instrumentation used for data capturing:* important to maintain the integrity of the data.

External factors that can impact the depth, location and available resource:

- *Shipping routes*: The presence of the Agulhas shipping route must be taken into consideration when analysing the resources for any technology installed for energy extraction. This technology must be located at least 20 m below the surface to allow sufficient clearance from the ship drafts.
- *Commercial Fishing Activities*: Fishing activities, commercial and subsistence

would impact the siting of turbines and should have as low as possible impact on the local fishing community.

- *Existing infrastructure that can consume the generated energy*: the existing power grid will play a large role in determining the placement of the turbine farm.
- *Marine Protected Areas*: These areas cannot be used as suitable sites.

The published raw data that is available lies within the required mooring depth. Figure 1 illustrates the 4 data capture locations. This data was used to analyse the Agulhas Current.

Figure 1: Points of available data

In order to determine sites of promising capacity, first a basic analysis of the temporal velocity data obtained by each ADCP averaged over the time period is carried out. Then, when the promising sites have been determined, a full temporal analysis will be carried out. A mean value of 1.2 m/s has been chosen to identify promising sites, for this indicates that the current will flow at speeds applicable for marine turbines for a large portion of the operating time. This will be confirmed with capacity factor analysis.

4. RESULTS

4.1. Overview of all Sites

Table 1 contains the basic statistical analysis for each site at a depth of 20 m from the ocean surface.

When examining the values achieved from the statistical analysis, it is seen that Location 1 and Location 2 prove to be the most promising sites. From Figure 2 it is seen that the Location 2 will be the better choice in respect to proximity to the nearest substation. Figure 2 also shows protected marine areas, which have to be taken into consideration when implementing the turbine farm. These areas should not pose a problem, as the direct cabling lines from both chosen sites would not run through the protected areas.

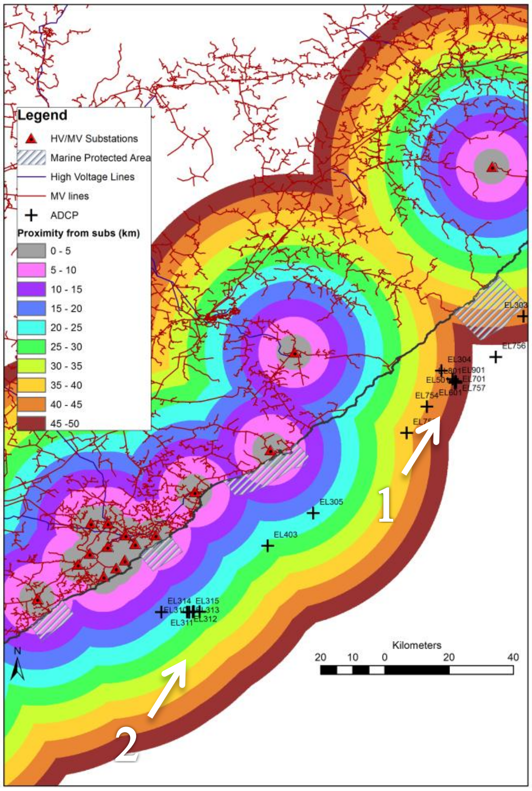

Figure 2: The two promising locations are shown with respect to the electricity grid and marine protected areas

	Location 1		Location 2	Location 3	Location 4
Location	-32.50733, 28.83183		-33.150 28.099	-31.196, 30.175	-33.703, 27.298
Time Period	2006/05/11 - 2007/06/05	2009/03/23 - 2010/09/13	2007/08/18 - 2009/03/22	2005/09/08 - 2006/09/09	2008/04/01 - 2010/03/04
Sea bed depth [m]	84.16	84.16	85	61	92.2
Mean [m/s]	1.48	1.46	1.4	0.95	0.97
Median [m/s]	1.59	1.6	1.54	1.03	0.94
Standard Deviation [m/s]	0.53	0.59	0.61	0.42	0.54
Maximum [m/s]	2.7	2.82	2.83	1.92	2.77

Table 1: Basic Statistical results of all location

A temporal analysis is carried out in the two selected areas to further investigate the current variability and the occurrence of Natal Pulses.

4.1. Location 1: Cape Morgan

At Location 1, two sets of data have been captured. The first (data set A) was captured from 2006/04/11 to 2008/04/30 with the use of a Nortek ADCP and the second (data set B) was captured from 2009/03/23 to 2010/09/14 with the use of a RDI 300 ADCP. Both data sets are examined at a depth of 20 m.

Table 2 shows the statistical properties of the velocity of each data set and shows that the respective property values coincide well even though the data sets have been collected during different time periods.

Figure 3 to Figure 6 show the velocity and directional data for each data set. It is seen in Figure 3 and Figure 4 that there are two occasions where the velocity drops significantly and the direction changes for approximately 20 days. These instances can be seen at 2006/05/11 and at 2007/06/05. This drop in velocity and change in direction alludes to the presence of Natal Pulses.

Property	Data Set A	Data Set B
Mean [m/s]	1.48	1.46
Median [m/s]	1.59	1.6
Mode [m/s]	1.44	1.76
Standard Deviation [m/s]	0.53	0.59
Minimum [m/s]	0.009	0
Maximum [m/s]	2.7	2.82

Table 2: Location 1

In this two year period that is analysed, only two Natal Pulses are seen. Whereas in the 18 month period analysed from 2009/03/23 to 2010/09/14 there are three Natal Pulses, all seen consecutively in a 7 month period. With reference to the found yearly average frequency of occurrence of 1.6 it is seen that abnormally large quantity of pulses occurred during this period. This highlights the irregularity and unpredictable nature of this phenomenon. The presence of smaller eddies are seen through the variations in velocity which lasts approximately a day.

The probability of exceedance plot for Location 1 is shown in Figure 7.

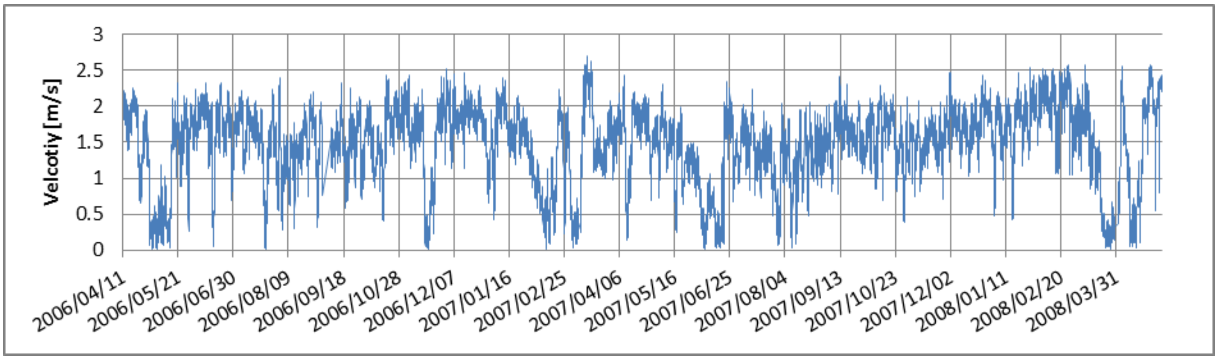

Figure 3: 24 month temporal velocity plot for Location 1, data set A

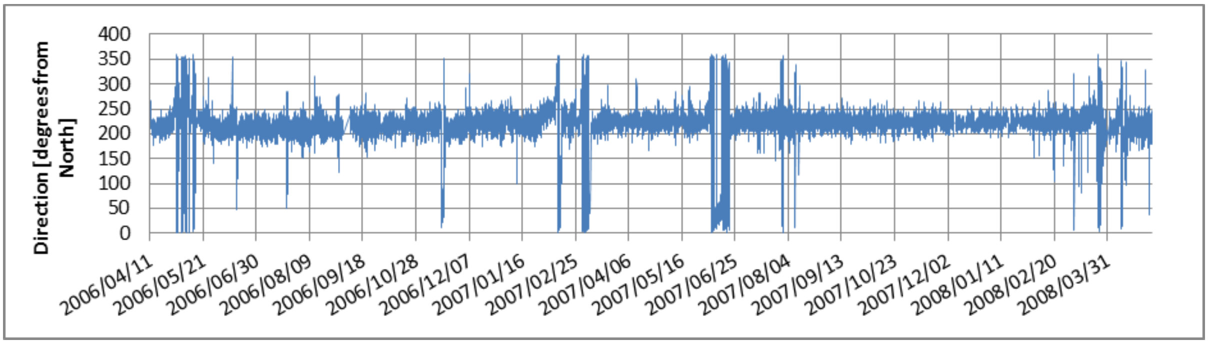

Figure 4: 24 month temporal directional plot for Location 1, data set A

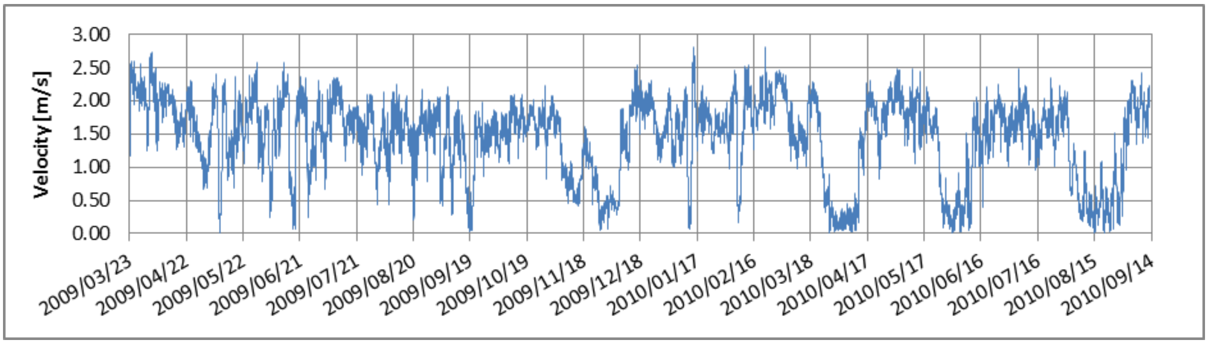

Figure 5: 18 month temporal velocity plot for Location 1, data set B

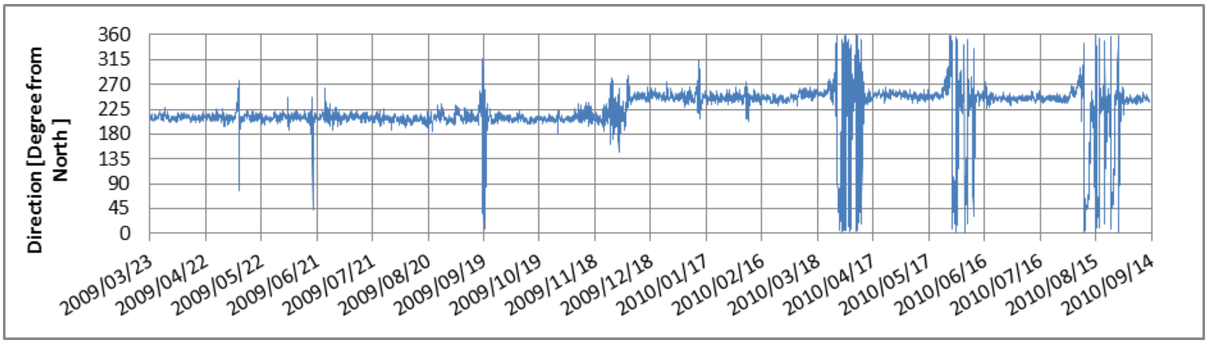

Figure 6: 18 month temporal directional plot Location 1, data set B

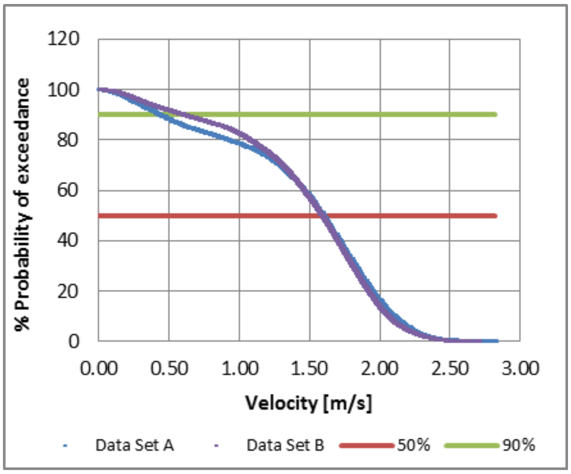

Figure 7: Exceedance of probability plot for Location 1

Figure 8 and Figure 9 show a histogram of the data and the normal distribution plot of the velocity data respectively. The two distinct peaks in the histogram curve show that the low velocity data component can have a negative impact on potential power extractable from the current. It is seen that the normal distribution plot is skewed slightly to the left, again reiterating the presence of low velocity occurrence. The wide bell observed in Figure 9 indicates the large variability of the current.

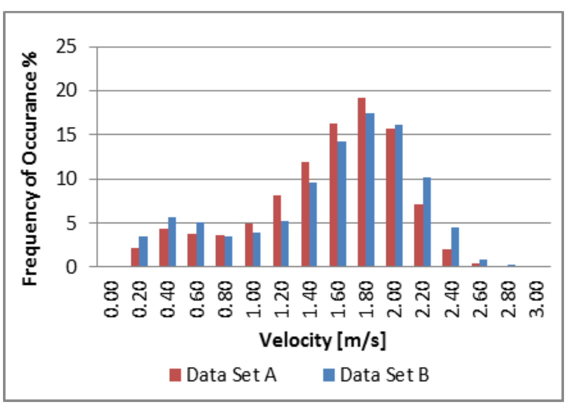

Figure 8: Histogram of velocity data for Location 1

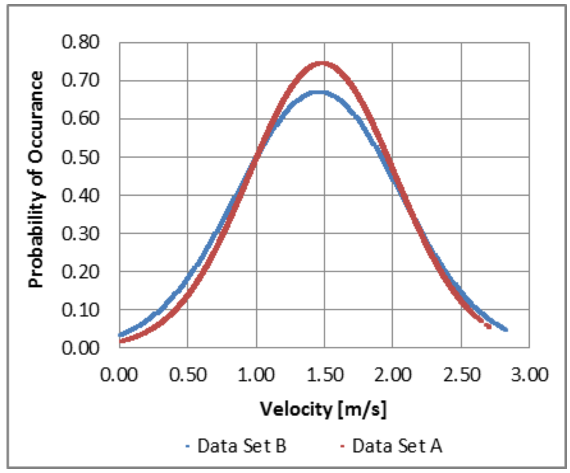

Figure 9: Normal distribution curve of velocity data for Location 1

4.2. Location 2: East London

The analysis for the data at Location 2 can be seen in Figure 10 and Figure 11. The data set runs from 2007/08/18 to 2009/03/22 and was captured by a RDI 300 ADCP. The standard deviation and mean for this data set can be seen in Table 3. It is seen that the mean velocity for this data set is less than Location 1 and the standard deviation is higher. This large standard deviation is illustrated in Figure 10 where the velocity does not tend to a constant value even when there are no Natal Pulses present. One can see the presence of three Natal Pulses in this time period.

Property	**Value**
Mean [m/s]	1.40
Median [m/s]	1.54
Mode [m/s]	1.67
Standard Deviation [m/s]	0.61
Minimum [m/s]	0.01
Maximum [m/s]	2.83

Table 3: Location 2

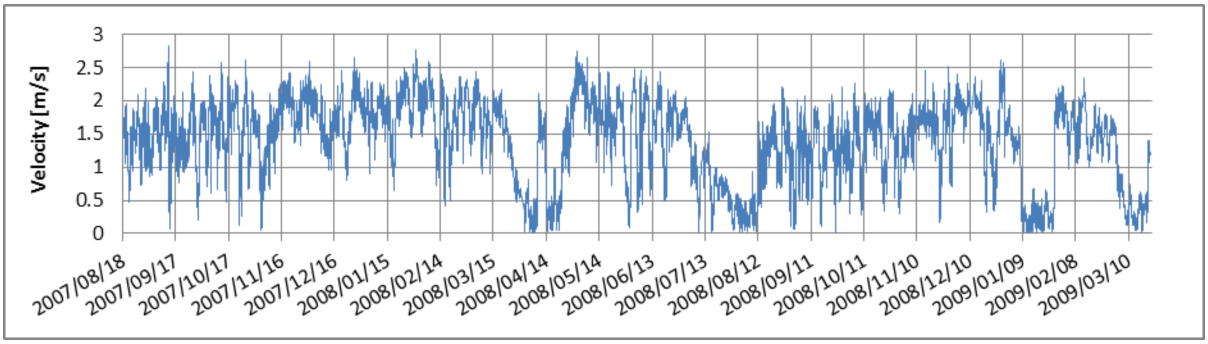

Figure 10: 19 month temporal velocity plot for Location 2

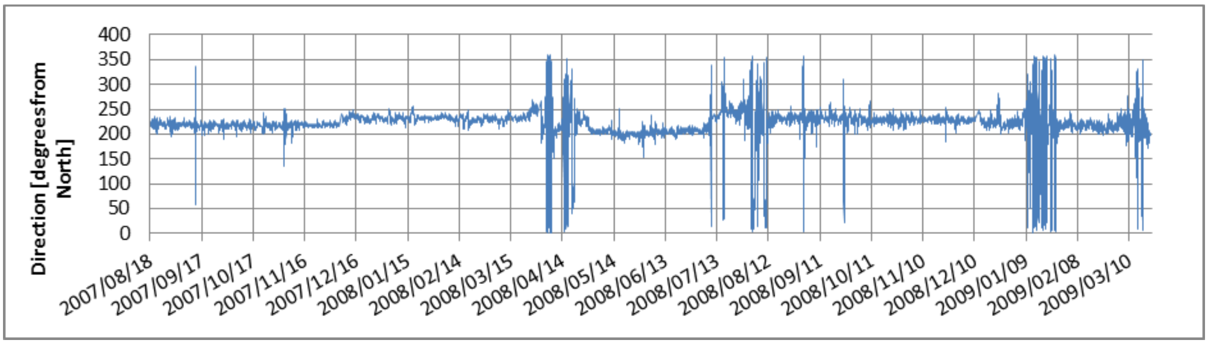

Figure 11: 19 month temporal velocity plot for Location 2

Probability of exceedance can be seen in Figure 12.

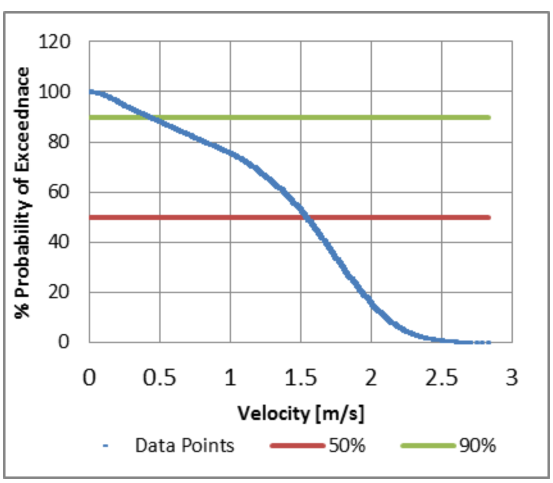

Figure 12: Exceedance of probability plot for East London Location 2

Figure 13 and Figure 14 show a histogram and the normal distribution plot of the velocity data.

Again, the presence of the low velocities seems to skew the curve.

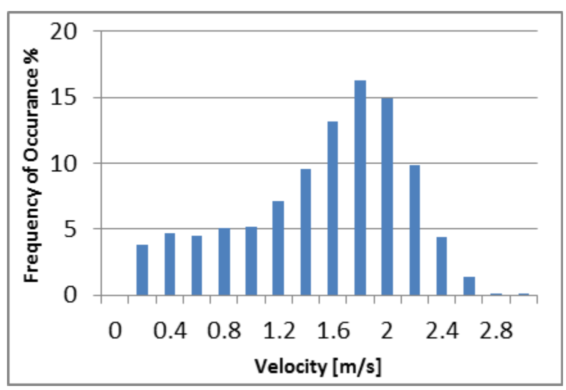

Figure 13: Histogram of velocity data for Location 2

From the three time periods which have been analysed, it is found that the direction of the current remains constant, with exception being during the passing of a Natal Pulse and the infrequent passing of a day long eddy. However, a large variation in velocity outside the regions of the Natal Pulse is observed, thus an analysis is carried out with a numerical turbine where a capacity factor can be found. The capacity factor will be a better indicator of the impact of the variability of the current on expected power production.

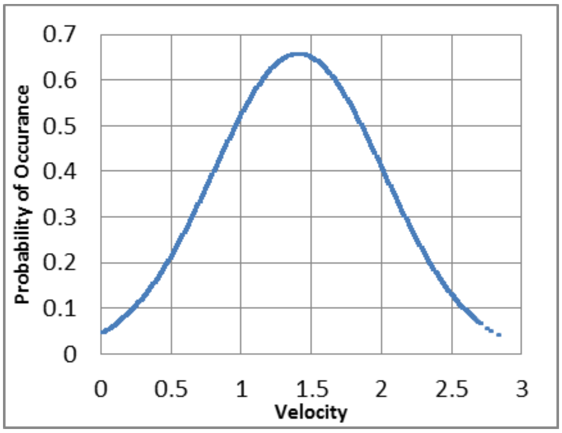

Figure 14: Normal distribution curve of velocity data Location 2

4.3. Possible Current performance

A basic numerical turbine model is set up and the capacity factor of the Agulhas Current is examined. The capacity factor gives a good indication of the variability of the site. Table 4 gives the numerical turbine specifications and Table 5 gives the obtained results after the numerical turbine has been implemented.

Turbine specifications	Numerical Turbine
Cut in speed	0.6 m/s
Cut out speed	2.0 m/s
C_p	0.4
Diameter	16 m

Table 4: Numerical turbine specifications

The values for the turbine are based on a generic marine turbine as the focus of this study did not include technology evaluation.

The capacity factor achieved using the SeaGen technology for 1 000 operational hours is 66% (Siemens 2012). The achieved capacity factors are considerably lower but this can be accounted for by the lower velocities experienced in ocean current applications and the variability of the Agulhas Current. These capacity factors are however of the same order, as what is typically expected from an offshore wind farm. They are also higher than onshore wind farms and PV installations.

Site	Capacity factor %
Location 1 Data Set A	50.8
Location 1 Data Set B	50.9
Location 2	47.5

Table 5: Achieved capacity factors

It must be noted that even with the presence of the three Natal Pulses in data set B, the capacity factor for this set of data is the highest and very close to that of data set A that contains only 2 Natal Pulses.

It is seen that Location 1 is the preferred site from a power extraction perspective however it is further from the nearest medium voltage station than Location 2. From Figure 2, it is seen that Location 1 and Location 2 lie 45 km and 25 km from the nearest medium voltage station respectively. The difference in capacity factor is approximately 3.3% between the two locations, but a techno-economic analysis will have to be carried out in order to see if the greater energy yield based on peak power will compensate for the costs incurred for the longer distance of sea cabling. Further, Location 1 has lower variability which results in a better location for marine turbine deployment.

5. CONCLUSION

It is clear that the Agulhas Ocean current holds an attractive source of renewable energy but due to variations in both the speed and direction of the current it cannot be considered to supply a constant (base-load) supply of energy. This is due to the current meandering as well as anomalies such as the Natal pulses that can reverse the direction of the current when present at a specific location. The computed capacity factor of 50.9% at Location 1 is however still high for a variable, renewable energy resource that could warrant exploitation, provided suitable technology can be developed to do this in a cost-effective manner.

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