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Resource assessment for the GEMSTAR tidal current energy harvester deployment in the strait of Messina

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***Abstract*—This paper concerns the present collaboration between the tidal technology developer, Seapower, and the global Engineering, Procurement and Construction (EPC) Contractor, Saipem. The two players plan to install a hydropower turbine in the Strait of Messina to generate electricity from the strong tidal current available there. The paper focuses on describing the tidal energy technology proposed, on the general description of the planned tidal project and on the prediction of the device performances from measured and predicted tidal stream velocities. Accordingly, the extractable annual energy from a specific site in the Strait of Messina is estimated. The site was preliminary selected based on available data on tidal current. Successively, ADCP measured data acquired in this specific location was used for obtaining year-long tidal current velocities using harmonic analysis. Results indicated that the site considered has a conspicuous available resource also showing minor inter-annual variability.**

***Keywords*—tidal energy, hydrokinetic turbines, tidal resource estimation.**

I. Introduction

THE Gemstar system is a hydrokinetic in-stream energy converter with a two horizontal-axis turbine configuration. The system is intended to be driven by slow-moving flows of water, namely tidal, marine or river currents. It is a submerged floating moored device with a lower impact on the natural environment compared to other technologies. The Gemstar can be lowered at its operating depth and raised to surface for periodic maintenance operations. It is stable in all circumstances, and it aligns itself to the different flow directions. Thanks to its design, it is also easily transportable, and it needs a short time to be deployed and recovered for maintenance purposes. These advantages make O&M costs particularly low. An illustration of the Gemstar system is reported in Fig. 1.

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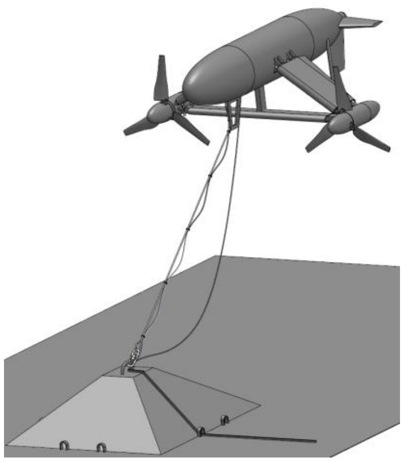

Fig. 1. GEMSTAR system general arrangement view.

Given the great tidal energy resource, the Strait of Messina is the most attractive area in Italy to install tidal turbines. Characterisation of the available resource is a fundamental step for the preliminary sizing of the tidal energy device and the estimation of the annual energy production. After a preliminary survey in the Strait, a set of experimental data was retrieved. Data for a short period was acquired at a specific site close to Punta Pezzo, a location with the highest peak velocity in the Strait. The data gathered concerns the velocity profile from the seabed to surface as a function of time. The profile gave useful information for site assessment purposes. After characterising the installation site, the device size was optimised and, through a performance prediction model based on empirical data and the tidal atlas, financial figures were also calculated.

Several aspects contribute to the attractiveness of the tidal energy resource. Primarily there is a significant amount of energy resource which is theoretically available at potential tidal energy sites. Another interesting aspect is related to the level of predictability of the tidal stream, compared to other renewable energy sources. Very accurate predictions of energy production can be obtained (provided a sufficient amount of data are available). In the area of the Strait of Messina, several estimations of the globally available resources exist. Studies on resource assessment related to this area are few [1] [2] [3] [4]. In general, the estimations on the practicably extractable tidal energy resource are very different from one source to another. Such difference highlights the need for detailed knowledge of local current characteristics in the Strait of Messina. Many constraints exist for defining possible tidal farm regions. For the specific concern of the environmental impact of tidal device installations, an investigation may be found in El-Geziry et al. [5].

Some of the results reported in this work will be related to current profile data related to the area of Punta Pezzo, located on the East side of the Strait of Messina close to the coast of mainland Italy, on which a preliminary assessment study has been performed.

In the future development of the project, a geotechnical and oceanographic survey will be performed on other potential areas of interest in the Strait of Messina. The extension to a whole farm with additional Gemstar devices installed will be evaluated technically, capitalising economically on the optimisation of results obtained from the first unit installed.

Besides, worldwide locations with high electricity needs like island locations represent suitable opportunities; a global EPC contractor can provide the logistic support, scout the local fabrication yard and supervise the construction, install the device following international standards and, finally, encourage the interest of additional clients.

II. MAIN CHARACTERISTICS OF THE SYSTEM

A. GEMSTAR System Configuration

Several possible concepts have been proposed for harnessing tidal current energy, and a high volume of technical literature has been produced on this subject. A brief review of general considerations and possible device configurations, for instance, is provided by Vikas et al. [6]. Another review of several types of tidal systems is provided by Roberts et al. [7].

Gemstar is a tethered floating system supporting two hydrokinetic turbines with the capability of self-alignment with the current stream. It may be equipped with a self-towing winch, which is capable of setting the desired operating depth. It has a limited impact on navigation and is linked to the seabed through a flexible mooring system.

The equilibrium at a proper working depth (with a suitable clearance from the seabed) is obtained by using the buoyancy generated by a main floating body, which balances the thrust acting on the turbines and the drag on the structures during operation. A proper mooring system is applied in order to restrain the device's floating motion.

Several mooring configurations are possible. A basic arrangement of a single anchoring point on the seabed is used, allowing the rotation of the floating structure in response to current direction change. Other configurations are also possible with different anchoring arrangements using more mooring cables, for example in order to reduce the required buoyancy or space occupation or to increase safety clearance.

The designed configuration may reduce maintenance costs and simplify deployment operations. The system can be easily raised to the surface for maintenance, by slowly releasing the mooring cable. Possible strategies to improve the deployment operations are under development with the support of the EPC contractor: its experience within offshore installations and underwater structures can reduce both CAPEX and OPEX on several areas like mooring system, control system, automation and more.

Two generators are installed on board and mounted on the turbine shafts through a gearbox. Each generator is electrically controlled by an inverter, used for grid connection purposes and to obtain optimal working conditions at different current speeds. Suitable control logic is also implemented to pursue optimal operating conditions during the change of flow direction. The power connection is provided using a power cable, which is fixed onto the mooring cable and extended up to an on-shore grid connection point.

The patented system has been developed since 2005 after a research project, named initially GEM, which has seen the cooperation of some other different entities.

B. Gemstar project development

Following results from the previously developed GEM device, the Gemstar project involves extensive R&D, during which different sessions of experimental and numerical tests have been performed. Research activities have been mainly carried out at the University of Naples "Federico II", also thanks to public funding.

The following table reports the different experimental set-ups for the main development stages. In the end, a large-scale prototype was installed in a relatively low-speed tidal stream site in the Venetian Lagoon.

TABLE I
GEMSTAR DEVELOPMENT HISTORY: EXPERIMENTAL TESTS ON DIFFERENT SCALE PROTOTYPES AND COMPONENTS

#	Tests	Dimensions and scale
1	Bare turbine (2005) (laboratory)	Rotor diameter: 1.20 m
2	Bare and Shrouded turbines (2008-2010) (laboratory)	Rotor diameter: 0.6 m
3	Complete floating system (2010 - 2011) (laboratory)	Rotor diameter: 0.6 m (different configuration tested)
4	Full scale prototype (2012) (sea environment)	Rotor diameter: 3 m

Details on previous developments of the project and on the main results are described by Coiro et al. [8]. However, the project is still in progress, and a new test installation with a larger rated power prototype is planned in the Strait of Messina. Given this intended installation, a preliminary resource assessment is scheduled with a survey of the current regimes in some strategic areas of interest within the Strait. However, for initial estimations, a set of data already acquired corresponding to the energy site of Punta Pezzo was used in the present work to fulfil a preliminary energy production assessment.

Different configurations of the system were considered. In particular, in the previous work, a shrouded turbine arrangement was used to increase the effective energy conversion efficiency (information about shrouded systems are reported by [9], [10]). The shroud is a toroidal shaped component with an aerofoil section, placed around the turbine and acting as a diffuser. In principle, it is able to largely increase the conversion efficiency, at the cost of an increase of the total frontal area and of the global thrust. Its economic effectiveness is, however, still questionable. In the configuration actually under development, the use of the shroud will probably be rejected in consideration of the following issues:

- cost increment, due to the production of a complex shape part;
- thrust increment (with a significant increase in the buoyancy required).

C. *Power production performance*

The main results of the tests may be represented in terms of the non-dimensional power coefficient, C_P, as defined by the following relation:

$$C_P = \frac{P}{\frac{1}{2}\rho V^3 S} \tag{1}$$

where P is the output power, ρ is the water density, V is the current velocity and S is a reference surface, generally assumed as equal to the turbine rotor disk area. The power coefficient is generally reported as a function of the tip speed ratio (TSR), defined as the ratio of the turbine peripheral speed, ΩR, to the flow asymptotic velocity:

$$TSR = \frac{\Omega R}{V} \tag{2}$$

For the non-shrouded solution, the bare turbine power coefficient, based on mechanical shaft power, is reported in Fig. 2. Reported results refer to a small scale model of the whole floating system.

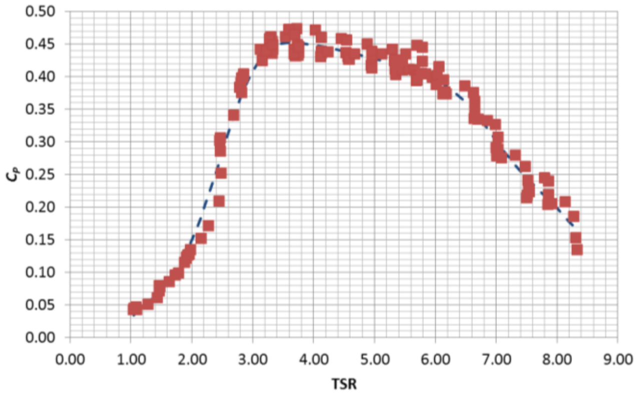

Fig. 2. Power coefficient for bare turbine mounted on GEM floating system model. Red dots are the experimental measurements and the dotted line represents cubic-spline fitting.

A maximum power coefficient value of about $C_{Pmax} = 0.45$ may be observed at approximately $TSR = 4$. Such figures may be used to estimate the required dimensions of a device for a desired rated power. Considering also the mechanical, η_m and electrical, η_e, conversion efficiencies, a further output energy reduction may be accounted for by the global efficiency:

$$\eta = \eta_m \eta_e = 0.81 \tag{3}$$

In order to exploit the maximum available energy, it may be considered a device with cut-out speed equal or slightly higher than the maximum speed expected in the installation site.

In order to define, at a preliminary stage, the device's characteristics, some assumptions had to be done on the control system. In the present study, it is assumed that the control system can track the optimum power coefficient condition up to a given current speed (rated speed), above which the power output is held constant at the generator's rated power. To fulfil this condition, proper design of the turbine and a suitable control strategy are required, also in order to limit the rotational speed. Specific studies on this topic, for a fixed pitch turbine, may be found in [11] and [12])

With the above assumptions, a device with two turbines for a global rated power of 300 kW requires a turbine disk diameter of about 12 m, in a current site with approximately 3 m/s maximum speed, with a rated current velocity of approximately 2 m/s.

An estimation of the desired power curve is reported in Fig. 3.

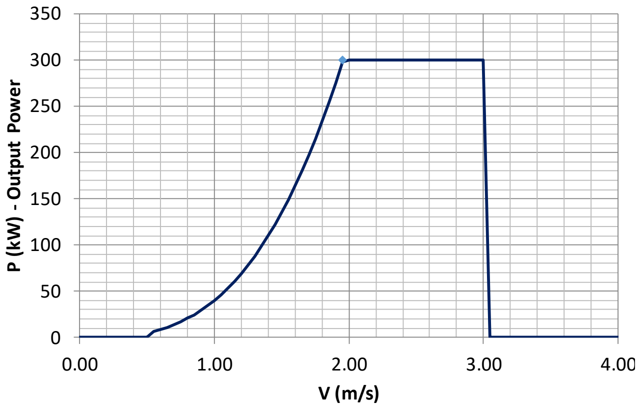

Fig. 3. Power curve of a possible GEMSTAR device with 12 m diameter turbine.

From Fig. 3 above, some specific operating limits may be observed: the cut-in speed, above which power production starts; the nominal speed, at which the power is held constant at its rated value; and the cut-out speed, over which the turbines are taken to rest, to comply with the generator's operating limits.

III. STRAIT OF MESSINA CURRENT CHARACTERISTICS

D. Tidal table data

Every energy tidal stream site has different characteristics. Thus, it is essential to initially investigate the characteristics of the location of interest to perform an estimation of expected energy production. First, we have to gather information on actual local current behaviour. A general trend of the velocity distribution over the area of the Strait could be retrieved in a preliminary approach by using the available historical data, for example as reported in available tidal tables of the Italian Hydrographic Institute [13]. Available tidal tables are based on the historical data source obtained mainly in 1925 by Vercelli [14]. A general overview of the velocity in some sites within the area of the Strait is reported in Table II [15].

TABLE II - MAXIMUM SURFACE CURRENT VELOCITY FOR SELECTED EXPLOITABLE AREA ACROSS THE STRAIT OF MESSINA

Reference Site	Lat. (N)	Lon. (E)	Vmax (m/s)
Punta Pezzo	38°14'00"	15°38'00"	2.95
Scilla-C. Peloro	38°15'48"	15°41'00"	*0.60*
T.Cavallo-C.Peloro	38°15'24"	15°40'00"	1.19
Ganzirri-P. Pezzo	38°14'30"	15°37'24"	2.53
NW of T. Cavallo	38°15'00"	15°40'40"	1.60
Villa S.Giovanni	38°11'46"	15°37'55"	2.39
Ganzirri to T. Faro	38°15'24"	15°37'54"	2.17
S. Agata	38°14'54"	15°36'24"	1.83
Pace	38°14'09"	15°35'12"	1.61
SW T. Cavallo	38°14'42"	15°40'39"	1.19
NW Scilla	38°15'21"	15°42'39"	*0.42*
NE C. Peloro	38°16'21"	15°39'33"	1.81
S. Raineri	38°11'30"	15°34'32"	2.39

The most promising area is located close to Punta Pezzo, which has an annual maximum flow speed of about 2.95 m/s. More recent tidal tables report similar values for this site; however, some overestimation may be expected compared to the actual current speed at exploitable sites.

As indicated in the tidal atlas, at Punta Pezzo a permanent current flows from North to South and has a fixed module of 0.36 m/s. Each site of the Strait presents a different permanent current value also affected by related meteorological effects. The presence of such a component may also have effects on velocity prediction and related energy production estimates.

The power available in the current flow varies with time according to the variation of flow velocity. The flow speed shows a characteristic time profile in the case of tidal regimes, following an almost cyclic variation induced by the periodic tidal motion. In the case of semidiurnal regimes, a typical pattern with approximately four peaks in a day may be observed, generally with four daily flow inversions.

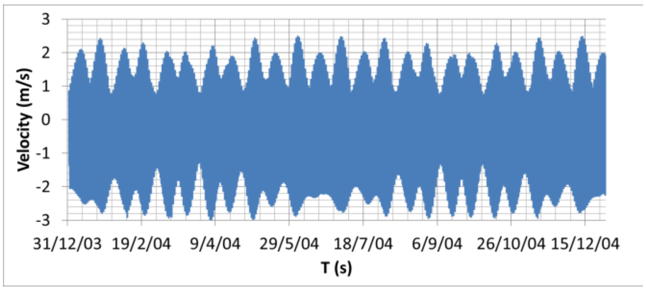

Fig. 4. Typical yearly trend of current speed in a semidiurnal tide site.

Fig. 4 reports a typical yearly trend, reconstructed from the available historical data of tidal tables [16]. This figure reports an interpolation of peaks and slacks of tidal current.

The previous figure shows the sequence of multiple peaks, increasing and decreasing throughout the year, mainly due to astronomical effects. Positive and negative values represent the two main directions of the current flow, reversing according to tidal motions. A typical series of alternating peaks may be observed, corresponding to spring and neap tidal peaks.

On a daily timescale, a typical semidiurnal pattern may be recognized, with two inversions of the current direction, as reported in Fig. 5.

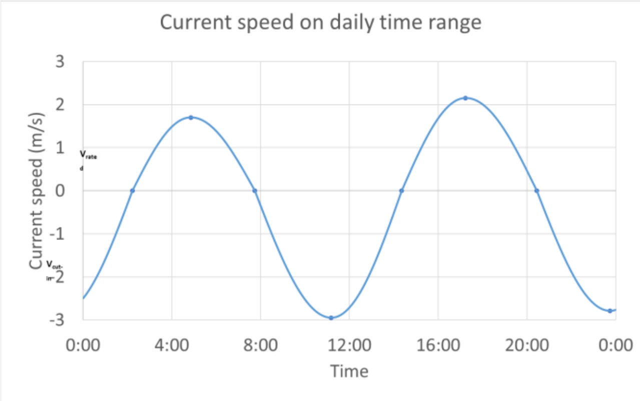

Fig. 5. Trend of current speed in a semidiurnal tide site during a single day.

The trends reported in previous figures are based on the interpolation of tidal table data and only give a basic reference for the overall current climate. Long term measured data may give a more accurate representation of specific installation sites. On each interval between peaks and slack water points, the considered interpolation approach uses sinusoidal functions. Such functions pass through the peak velocity data which must be known for the time interval over which the interpolation is applied (in this case peak data are obtained from tidal tables).

E. *Measured current speed data*

A relatively short time data acquisition was obtained by using ADCP (Acoustic Doppler Current Profiler) equipment deployed in a site near Punta Pezzo, in order to carry out a more detailed investigation of local current characteristics. The observation period extends over approximately 24 days. A lower peak velocity, compared to tidal tables data, was observed (even if the limited time extent increases the uncertainty in peak measurement estimations).

Fig. 6 reports the measured data at a depth of about 17 metres. Data are sampled with a 2-minute acquisition interval.

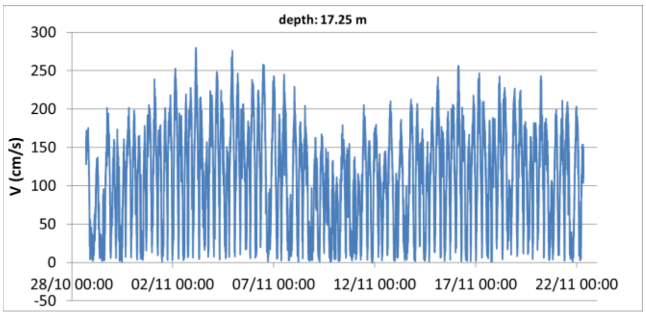

Fig. 6. Measured speed ADCP data near Punta Pezzo.

In this case, too, a typical four-peaks daily pattern may be observed, as shown in Fig. 7.

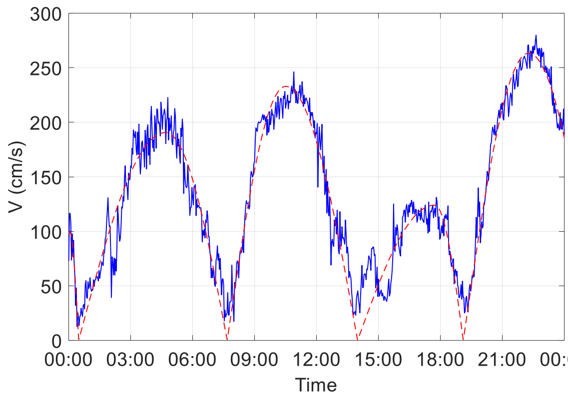

Fig. 7. Measured speed ADCP data near Punta Pezzo. Daily timescale observation interval.

F. *Harmonic analysis and tidal stream prediction*

Successively, a harmonic analysis was also carried out to analyse the tidal stream behaviour in the time-domain and successively predict it. The input of the analysis can be the measured flow speed data or current speed value data obtained from tide atlas. The output of the analysis facilitated the performance of the estimation of the flow speed outside the measurement interval or, in other words, for the whole year. In order to perform these tasks, the "t-tide" MATLAB tool was used [17]. This program is widely adopted throughout oceanographic studies to analyse and predict the tide elevation. In order to use this tool for predicting the stream speed, a series of further operations were performed. These concerned preparing the input tidal stream record. For this purpose, the component of the constant marine current of the Strait was also initially filtered out. The fixed component was added later on to the tidal stream prediction.

With the methodology implemented, the tidal stream velocity can be estimated as a superposition of sine functions, considering several harmonic components defined by amplitudes and phases [17]. Such analytical representation is obtained from experimental observations for a considered site, after identification of site-specific harmonic constants. The resulting analytical model may be used to estimate the velocity over a chosen period of any length, either in the future or in the past.

We report in Table III tide results in terms of amplitude, period and phase for the firsts 20 constituents obtained from the harmonic analysis based on for Punta Pezzo. The constituents are ordered by their amplitudes, which are also reported in Fig. 8. It is worth to note that the reported constituents are given by the harmonic analysis applied to the current velocities values and not to the tide elevation data.

TABLE III
SUMMARY OF HARMONIC ANALYSIS RESULTS.

Constituent name	Amplitude m/s	Period h	Freq. cph	Phase deg
M2	1.555	0.517	0.081	104.470
S2	0.443	0.500	0.083	147.100
K1	0.389	0.997	0.042	73.780
N2	0.243	0.528	0.079	84.870
O1	0.195	1.076	0.039	30.060
M4	0.156	0.259	0.161	32.030
K2	0.147	0.499	0.084	147.000
P1	0.140	1.003	0.042	73.330
P1	0.129	1.003	0.042	80.850
K2	0.121	0.499	0.084	169.500
M6	0.064	0.172	0.242	313.740
2MS6	0.046	0.171	0.244	355.610
2MK5	0.034	0.206	0.203	284.700
2MN6	0.023	0.174	0.240	295.300
2MK6	0.016	0.170	0.245	354.840
MF	0.015	13.661	0.003	78.990
MK3	0.014	0.341	0.122	3.610
MK4	0.013	0.254	0.164	77.440
MS4	0.012	0.254	0.164	62.270
MSM	0.012	31.812	0.001	170.010

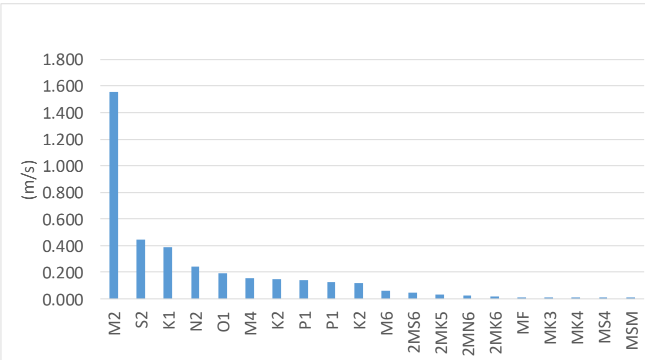

Fig. 8. Amplitude of first 20 constituents from harmonic analysis.

Fig. 9 shows a comparison of measured and predicted flow speed values. These values correspond to a period for which experimental measurements were conducted. Data was logged with an ADCP positioned at site offshore Punta Pezzo at a depth of 40 metres. The instrument was deployed for 24 days, during November 2013. The lower plot of Fig. 9 zooms for a five-day time interval. Here it can be noticed that the prediction model efficiently predicts the tidal flow measurements.

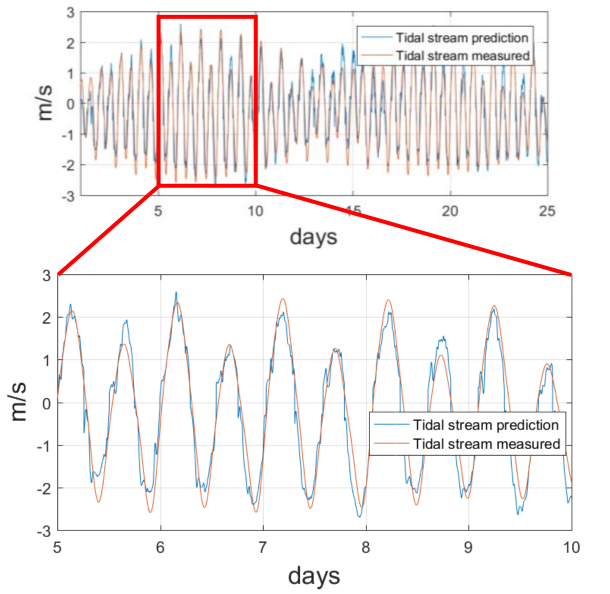

Fig. 9. Comparison between the predicted tidal stream velocity from the harmonic analysis method and the measured flow speed values.

Minor differences, between measured and estimated current speeds, exist only at moments corresponding to peaks. In order to correctly quantify how much the estimation is valid for our needs, it is essential to understand how much the uncertainty in estimating or measuring the tidal flow would affect the energy-absorbed calculations. For this ultimate purpose, a complete uncertainty analysis is required.

Despite this, for preliminary estimations, as per the objectives of this paper, a simplified assessment of the error is performed. Thus, we calculated the energy available within a circular area of 1 m^2 for both predicted and measured flow.

In Fig. 10 is illustrated the power calculated from the two different flow speed sets of values (measured and predicted flow velocities). It can be noted that the maximum discrepancies are observed again at the peak values. However, as the power is proportional to the cube of the velocity, especially for peak values, the discrepancies are more evident with respect to peaks related to the comparison of flow velocities (Fig. 10). After integration over the entire 24 day period, it was found that the energy obtained with the prediction model over-estimates the energy calculated using measured data by a value of 3.34%.

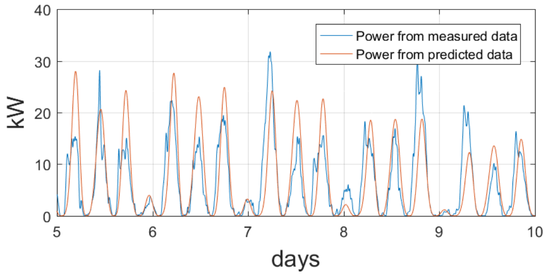

Fig. 10. Power in one square-meter circular (cross-section) area available in tidal stream, calculated from measured and predicted flow speed values; velocity data obtained from the harmonic analysis method.

G. *Gemstar's energy conversion estimations*

In order to estimate the power that can be absorbed from the Gemstar system, the device characteristics reported in Table IV were considered.

In the performed prediction analysis, the model used for the calculation of flow velocity also has an important effect on energy estimation. In order to highlight the effect of flow speed data modelling, the energy estimation obtained from tidal table data interpolation (see section D) are compared to the results based on the harmonic analysis approach (section F).

TABLE IV – GEMSTAR PARAMETERS

Description	Value	Unit
N. rotors	2	-
Rotor radius	6	m
Cp	0.45	-
Efficiency	0.77	-
Cut-in speed	0.5	m/s
Cut-out speed	3.0	m/s
Rated power value	300	kW

The generated output power is zero below cut-in speed, whereas, above the rated speed, power output is limited to the maximum generator rated power value. If velocity increases beyond the cut-out speed, turbine operation is arrested, and output power is null. In Fig. 11 the velocity trend is reported, showing the sequence of peaks and slack water moments on a daily timescale, for the interpolated tidal table approach.

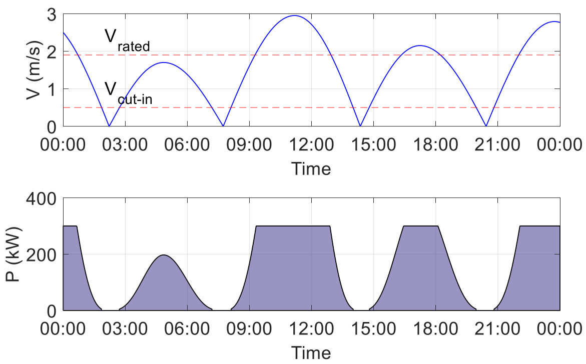

Fig. 11. Typical daily trend of current speed in a semidiurnal tide site (from tidal table data interpolation method) and related tidal turbine power output (power curve in Fig. 3).

For a single device plant, the energy production assessment is established thanks to the flow speed time-based profile $V(t)$ and to the power curve $P(V)$ of the system under consideration. Starting from the tidal time series of a particular site in a certain period $\Delta T = t_f - t_i$, and assuming an almost steady behaviour of the conversion system, it is possible to assess the available energy, E_a, integrating power over time:

$$E_a = \int_{ti}^{t_f} P(V(t))dt \tag{4}$$

where the available power P is estimated by taking into account the device power curve.

Using the method based on the interpolation of tidal table data, retrieved from the tidal atlas for the site of Punta Pezzo, a first estimate of the available energy is given to be $E_{a0} \cong 890\, MWh/year$. At this location, the peak velocity is about 2.95 m/s.

Several reasons may contribute to the uncertainty of such estimation. These may be, for instance:

- Local variations due to seabed morphology;
- Variation with depth due to the influence of the seabed;
- Inherent tidal table estimation errors;
- Permanent current variation and meteorological effects;
- Effect of unclean blade surfaces and turbulent flow;
- Interpolations and numerical integration errors.

In the tidal data interpolation approach, the time history of the velocity was locally interpolated between the peak points by means of sinusoidal functions.

Considering the harmonic analysis method, on the other hand, the flow speed can be estimated by means of a trigonometric series, whose coefficients (amplitudes and phases) are obtained by fitting such analytical model to a set of experimental data over a given time interval (in this study the 24 days' ADCP data campaign is considered). As also previously indicated (section F), the obtained analytical function can be used to predict the velocity over a chosen period of a given length. In this case, the velocity was predicted over a one-year interval, in order to estimate the related energy production.

For illustration purposes, in Fig. 12 is shown a 3-day profile of the theoretical power outputs, obtained both from the measured flow velocities and from the predicted velocity data based on harmonic analysis.

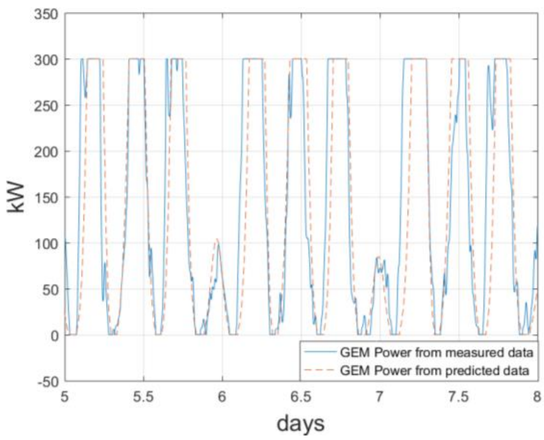

Fig. 12. Typical trend of power output in a semidiurnal tide site (based on device characteristics reported in Table IV). Predicted data are based on flow velocity from the harmonic analysis method.

The energy estimation based on predicted velocities overrates by 3.59% the energy calculated using measured values.

However, by using the tidal harmonic analysis prediction model, explained above and applied to the whole year, a significantly lower energy estimate has been determined compared to the estimation based on tidal atlas data. The preliminary assessment based on the interpolation of tidal table data estimates 35% more energy compared to the prediction method based on harmonic analysis.

By using the implemented prediction model, we calculated the energy production for three consecutive years. In order to provide a figure of the year-to-year fluctuations of available resource, we report the estimated Annual Energy Production (AEP) in Table V.

TABLE V - .ENERGY PRODUCTION ESTIMATIONS USING THE PREDICTION MODEL (PUNTA PEZZO SITE)

Year	AEP (MWh)
2019	681
2020	675
2021	680

IV. SITE PREPARATION, DEPLOYMENT, OPERATION AND MAINTENANCE

H. Site preparation

The selected site for the Gemstar anchor installation will be monitored with an underwater camera and will be cleared of any possible debris. The anchor type to hold in place the Gemstar will be chosen based upon soil condition results and dynamic mooring analysis results. The anchor will be installed with a suitable lifting vessel, and its holding capacity will be proved for at least 15 minutes with a pulling force at anchor equal to at least 1.25 times the design tension at the anchor. The anchor will be either of the drag embedment type or most probably a gravity type; it will be installed with the use of an Anchor Handling Tug (AHT).

I. Transportation and installation

Offshore operations are warranted by a third party, the Marine Warranty Surveyor (MWS), who ensures that all activities are executed safely and in compliance with existing standards. MWSs are generally appointed by the final client or by the installation subcontractor in the absence of the former. It will be the EPC contractor’s duty to ensure that all documentation is readily available to the MWS for approval prior to transportation and during the installation.

A HAZID (Hazard Identification) meeting will be called well before the start of offshore operations in order to evaluate any possible related risks and to find mitigation measures that will make the installation safe. The likelihood and possible consequence of different hazards will be evaluated by creating a risk matrix.

Typically, offshore operations require good weather conditions to perform any type of activity safely; typical industry maximum Hs to perform some typical activities are given in Table VI; the figures may change depending on wave period and according to the size of the vessel involved.

TABLE VI - TYPICAL INDUSTRY MAXIMUM HS FOR DIFFERENT OFFSHORE OPERATIONS.

Activity	Indicative maximum Hs [m]
Workability of Zodiac-Working Boat	1,5
Towing Line connection	3
Anchor handling	2
Barge mooring	1,5
Lifting/lowering from/to cargo barge	2

A suitable weather window, with the actual sea state lower than the maximum allowable, should be identified to ensure that each operation can be safely started and completed.

The Gemstar will be towed from the fabrication yard to the site using a tug; the device will be either wet towed or dry towed over the deck of a cargo barge with suitable strength and sufficient stability. Whichever option is chosen, met-ocean conditions will be defined for the transportation route in order to set the maximum forces the device will experience during the tow. In the event of dry tow, the transportation Hs and the barge size will define the maximum motions and acceleration to be used for the sea fastening that will keep the device in place; the motions and accelerations will be derived with a motion analysis using dedicated software or with empirical formulas. In the case of wet tow, sufficient clearance will be ensured to avoid any underwater hazard; the drag force of the Gemstar will be the main load to estimate. In any case, the tow will start only after a reliable good weather forecast has been obtained.

The selected tug for the transportation will comply with the minimum bollard pull requirements according to the MWS recognised standard. Shelter ports may be identified in case of sudden worsening weather conditions along the towing route; however, with short distances this option may be omitted. Throughout the transportation, the towmaster (tug master) is the person responsible for the overall conduct of the tow.

Once the Gemstar has reached the site, the transportation is completed; from that moment onwards, i.e. during the installation, the superintendent is the person responsible for the overall operation.

Remote Operated Vehicles (ROV) or divers will be used for connecting the mooring cable between the anchor and the Gemstar. The electric cable will be installed with a suitable supply vessel to bring to shore the electricity produced.

Finally, during the commissioning phase, the device will be tested in operation to make sure it performs as per specifications and to ensure all the monitoring systems are recording the required data.

J. *Operation and maintenance*

The Gemstar device will be operated for the first time on the Strait of Messina site. Therefore, even after commissioning, the device's performance will be continuously monitored. The electricity produced will be either sold to the grid or sold to a direct consumer with whom a sales contract would be entered into.

For the light maintenance, the Gemstar will be brought to the surface, and a tug or supply vessel will perform the required work. In case of heavy maintenance, the Gemstar will be first connected to a towing tug, then disconnected from its mooring cable and finally towed to a nearby harbour where the required repair works can be performed while the Gemstar is moored along the quayside.

V. CONCLUSIONS

This paper has shown how collaboration between Seapower and Saipem is bringing forward the development of a tidal turbine project within the Strait of Messina. While Seapower is making available its technology and performing a survey, Saipem could handle all marine activities, from transportation to the site to the installation and, finally, operation and maintenance of the device, ensuring compliance with offshore guidelines and safety standards and releasing the developer from this liability. The collaboration will be replicated for other potential sites and for the possible extension to a whole farm on the same site, ensuring interest from possible clients.

The first step of project development involves an investigation of the possible sites of interest for plant installation. In Italy, one of the most promising areas for tidal current exploitation is located in the Strait of Messina. A survey of some locations within the Strait is currently underway. The first results of a current measurement campaign were reported in the present paper, defining a preliminary assessment of the available tidal resource. One of the most interesting locations was identified on the Calabrian coast close to Punta Pezzo. A short time measurement (approximately one month) of the tidal current in this area was performed using an ADCP current profiler.

Based on the time histories of stream velocity and on a preliminary estimation of the device power curve, it was possible to estimate the expected energy production for a possible plant. A predictive model was used based on harmonic analysis of current time series. The model can use either the long-term tidal atlas data or the experimental data as input data and can be used to predict the velocity time history at any time interval of interest. A good agreement between predicted and measured data was observed.

After the first estimation of energy production based on interpolated tidal atlas data, some estimations based on the prediction model were reported. Model predictions yielded an expected energy production of about 680 MWh/year for the site of Punta Pezzo. Forecasted energy production little varies for different years. The investigated site for what concerns the resource available is one of the most attractive for possible plant installation.

In order to investigate other sites, further surveys are undergoing, also focusing on other relevant aspects such as local bathymetry and geophysical characteristics of the seabed.

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