Tidal Stream Power Development in San Bernardino Strait, Philippines

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***Abstract*— San Bernardino Strait is a passage located in the Eastern Visayas, Philippines, well-known for the strength of its marine currents. H&WB and SABELLA aim to develop the Philippines' and the ASEAN region's first commercial ocean power plant deploying tidal in-stream turbines, harnessing the energy of marine currents in San Bernardino Strait. The turbines will be connected to the electrical network of Capul, an off-grid island currently relying on a 750 kW diesel power plant. The first stage of the project consists in a 1.5 MW power plant featuring three SABELLA marine current turbine with a 20m rotor diameter, coupled with energy storage, as a reliable, sustainable and cost-competitive alternative to the fossil-based power generation. This pilot tidal power plant will be commissioned in 2021 for a 25-year operational lifetime.**

***Keywords*— Tidal stream power, project development, San Bernardino strait, insular energy model**

I. INTRODUCTION

In 2013, the Department of Energy awarded three leases in San Bernardino Strait for ocean energy harnessing to H&WB Asia Pacific, Filipino energy project developer. H&WB joined forces with SABELLA, French technology developer and marine current energy pioneer, in October 2015 with the signature of a Memorandum of Agreement. The aim is to develop the Philippines' and the ASEAN region's first commercial ocean power plant deploying tidal in-stream turbines, based on H&WB's project development experience and SABELLA's extensive technical expertise, combined with a real field experience acquired with two sea-proven marine current devices, D03 in 2008 and D10 in 2015. This paper outlines the development steps of the project, from the site characterization studies to the basic engineering works, the permits required for such project, including the environmental impact assessment and the social acceptation. Finally, the technical, economic, social and environmental stakes of the project will be highlighted:

II. SITE CHARACTERIZATION

A. *Site selection*

The San Bernardino strait is a narrow passage on the north-eastern side of the Philippine archipelago, separating the main islands of Luzon and Samar. As illustrated on 錯誤! 找不到參照來源。, the strait separates the islands of Luzon and Samar, and it is composed of four channels between the islands of Calintaan, Capul and San Antonio. Two phenomena are observed in the strait and interact with the topography and bathymetry to generate a flow regime of high intensity. First, the tides entail strong currents variating on a daily basis. The tidal regime in the strait is predominately semidiurnal with a diurnal inequality. Secondly, the Indonesian Throughflow (ITF), transporting water from the Pacific to the Indian Ocean, generate a large-scale flow with a unidirectional flux. As a consequence, current speeds reaching over 3 m/s during spring tides can be observed, which gives this site a high potential for tidal stream energy converters.

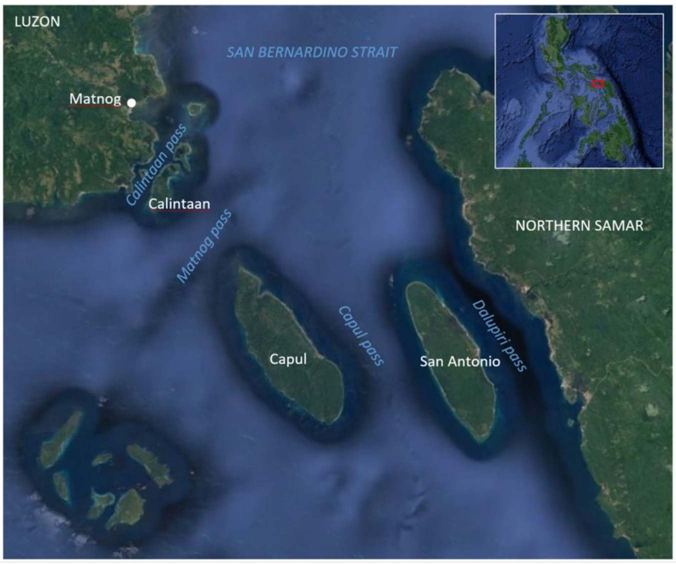

Fig. 1: San Bernardino Strait

B. *Resource assessment*

A preliminary resource characterization study was carried out in 2015 on the three concession areas in order to pre-select a suitable area for the development of the project. Further *in situ* measurements (bathymetry) and a high resolution numerical model led to a reliable estimation of the energy yield, which was combined to techno-econmical criteria such as grid-connection accessibility and power consumption, and designated Capul as the best choice for the first stage of the project.

1) *ADCP deployment - 2015.* Three Acoustic Doppled Current Profilers (ADCP) were deployed, one in each

concession area, for over thirty days (one Moon cycle). The data gathered were used to validate the numerical model. Another campaign will be planned on the location of the turbines on the selected installation site to confirm the yield.

2) *Bathymetric campaign - 2016. A* high resolution bathymetric survey (5-meter resolution) was conducted in 2016 in Calintaan, Matnog, Capul and Dalupiri passes using a Multi Beam Echosounder (MBES).

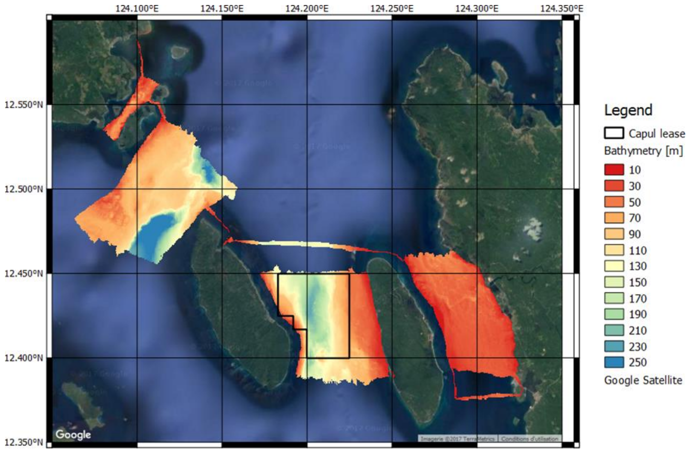

Fig. 2: high-resolution bathymetric chart of San Bernardino Strait (survey carried out in December 2016)

3) *3D hydrodynamic model - 2017.* In order to simulate the currents on the Strait, a 3D free-surface, hydrostatic, primitive-equation, terrain-following numerical ocean model was developed, over four embedded grids of increasing resolution (from 400m to 25m). The hydrodynamic model uses as forcings the Mercator Global Ocean analysis (1/12°) for the general circulation in the Philippines, the tide currents given by the TPX08 tidal model (1/30°) and atmospheric forcings by NCEP R2 (National Center for Environmental Prediction – Reanalysis 2 at 1.8°). The bathymetry was implemented using the *in situ* measurements (5m resolution), SRTM30 bathymetry and elevation data (30 arc second resolution) and a nautical chart with a 1:100 scale. Finally, ADCP measurements (2015) were used to validate the model.

4) *Yield.* The 3D numerical model calculates the current velocity at seven different altitudes in the water column. Based on the results, the kinetic energy resource of the current flow across a horizontal axis turbine is given by the following equation:

$$W = \frac{\pi}{4} . \rho . C_p . D^2 . V^3$$

Where ρ is the water density (1,024 kg.m^{-3}) – C_p the power factor – D the rotor diameter – V the current velocity.

C. *Lay-out*

In addition to the resource assessment, criteria on the flatness of the seabed, bathymetric limits and a minimum axial and longitudinal spacing between the turbines so as to avoid wake were taken into account when drawing the layout of the power plant.

Fig. 3: location of the tidal turbines and route of the export cables

III. PRELIMINARY FRONT-END ENGINEERING

A. *Fundamental technological principles*

SABELLA's turbine concept have been first developed since the 2000s, and further tried and tested through tow cutting-edge projects. First, in 2008 launched an experimental pilot project with its proprietary D03 turbine. Second, SABELLA successfully carried out the "D10-1000" test campaign, full-scale 10 meter rotor diameter and 1 MW prototype immersed in the Fromveur Strait and grid-connected in 2015 to the autonomous grid of Ushant Island, France. The design of the D20 turbine for the project in the Philippines is based on technological concepts tried and tested in operating conditions with D03 and D10, which, henceforth, constitutes the differentiating drivers of SABELLA's design (as illustrated on *Fig. 4*):

- A horizontal axis rotor with fixed symmetrical blades and no yaw drive. The absence of complex kinematics and system integration greatly reduces the need for maintenance, a complex issue in the subsea environment.
- A direct drive permanent magnet synchronous generator. Ruggedized and low speed steering system, with little maintenance needs, contrary to a gearbox-based electric chain.
- An in-board conversion and transformation system, allowing the mutualization of the power produced by different turbines on a subsea hub when the commercial stage is reached.
- A gravity-based tripod foundation, with a double benefit. First, it ensures a minimized environmental footprint at the end of the power plant lifetime; and, secondly, it facilitates the offshore installation operation as no soil preparation is required resulting in cost cuts, time saving and risk mitigation.
- A modular architecture dissociating the dynamic stability (tripod) and the energy production (nacelle and rotor) functions into two independent parts ingeniously inserted in a male-female cone-shaped mast without mechanical fixture. This configuration greatly simplifies recovery for

maintenance operations, as the only part to be manipulated is the turbine, much lighter than the heavy stabilization baseplate staying on site.

By focusing on a simple and ruggedized design, prohibiting any complex kinematics and system integrations leading to expensive maintenance, the machine reliability and availability is maximized and the MTBF (Mean Time Between Failures) is estimated at 10 years.

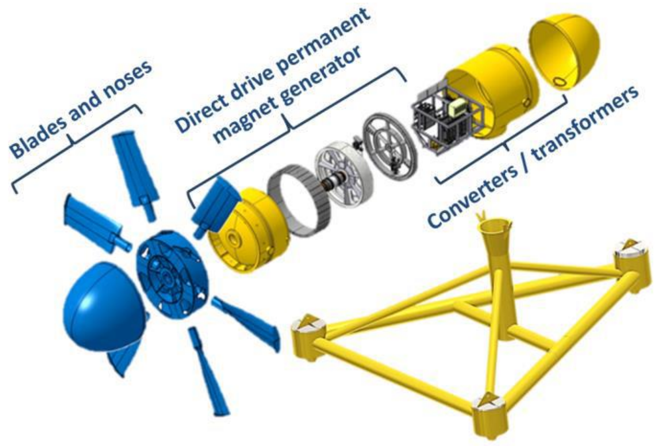

Fig. 4: breakdown of SABELLA's turbine components

B. *Tidal power plant architecture*

The first phase of the project consists in a 1.5 MW power plant featuring SABELLA's field-proven technology, coupled with onshore batteries for storage. Each turbine is a 20 meter rotor diameter device with a 500 kW rated output power. They will be deployed by 45 to 60 meter water depths. The electricity produced is exported to shore through three 7.5 kV export cables, one cable per turbine, approximately 1 km long, connecting the turbines to the substation. The export cables are also used for auxiliary power supply and host optical fibers for communication and bi-directional information transmission. A 1 MWh energy storage system (Lithium-Ion batteries) will be installed near the landfall point. The purpose of adding storage to the tidal power plant is two-fold:

- smooth the injection of the power production of the tidal turbines depending on the grid demand;
- secure the supply to the electrical grid so as to avoid blackouts.

IV. MAIN PERMITS

A. *Interconnection to the distribution network*

Consistent with the Philippine Small Grid Guidelines and the Philippine Distribution Code, a Connection Agreement will be entered with the Northern Samar Electric Cooperative (NORSAMELCO), currently in charge of the distribution grid in Capul, so as to connect the tidal power plant to Capul's network. Requisite to this agreement is the conduct of a Distribution Impact Study, which will establish that the project will not degrade the performance of the existing grid.

B. *Environmental Impact Assessment*

The consortium in charge of the project has to secure an Environmental Compliance Certificate (ECC) or a Certificate of Non-Coverage, to be issued by the Department of Environment and Natural Resources. To this end, a detailed Environmental Impact Assessment (EIA) must be carried out, starting with a Project Description Report (PDR). The EIA examines the potential environmental impacts associated from the interaction between the ocean power project and the environment from the pre-construction phase to the decommissioning phase. The study will identify and characterize the baseline conditions of the project site and the key project activities, predict and evaluate the likely environmental impacts toward the environmental variables and develop an environmental management plan which consist of adaptation and mitigating measures. The application for the ECC is expected during the third quarter of 2018.

C. *Social acceptance*

Several site visits were organized to meet with the host community and present the project. An initial public scoping was conducted in June 2017 with the local government unit (LGU, composed of barangays' representatives), and a public consultation open to all the citizens of Capul was held in October 2017, further to what the LGU issued the Resolution of Support as its full commitment in favour of the development and implementation of the Project. Regular public consultations will be held throughout the development of the project to keep the host community updated on the progress.

V. UPCOMING PROJECT DEVELOPMENT PHASES

A. *Financing*

The feasibility study of the project was completed. Before moving forward with the next engineering and construction phases, a focus is made on two aspects: the licensing and permits to be secured on the one hand, and the financial closing of the project on the other hand.

The revenues will be ensured by the electricity sells, as framed by the Power Supply Agreement (PSA) to be signed with NORSAMELCO. The PSA will define the electricity price covering the True Cost of Generation Rate, as negotiated with NORSAMELCO and approved by the ERC? The independent electricity regulatory body in the Philippines.

Philippine National Oil Company Renewables Corporation (PNOC RC), the renewable energy division of the Philippine National Oil Company, has recognized the potential of ocean energy exploitation in the Philippines and signed a Memorandum of Understanding with SABELLA and H&WB on October 27th 2016. This will help PNOC to reach its targets into the "after oil era" and to take a position in the promising new field of ocean energies. As NORSAMELCO is supposed to launch a call for proposals before signing a PSA with a new power producer, the process is estimated to last until the end of 2018.

B. *Engineering and design*

In parallel to the financial structuring of the project, the engineering studies will be carried out, starting with the basic design of the tidal turbines based on the bathymetric and hydrodynamic data obtained during the site characterization process and outputs of the high-resolution 3D numerical model. For instance, this phase includes the CFD study of the blades, the pre-design of the support structure and the preliminary analysis of the electrical architecture of the power plant. Then, the engineering team will refine the technological choices for the different components of the turbine (blade, nacelle, support structure, etc.) and the export system (export cable, onshore container) during the detailed design phase, which will last at least until the end of 2018 and up until financial closing.

C. *Procurement and assembly*

The procurement phase will begin once the detailed design is finalized and the financial closing of the project is achieved, estimated during the first semester of 2019. The different subparts of the turbine (upper part of the device) will be built in France:

- the rotor with the fiber reinforced plastic blades, front and rear noses;
- the nacelle containing all the electrical system from the generator to the in-board conversion/transformation system and related monitoring equipment;
- the export system, composed of the export cables and waterproof connectors;
- the Lithium-ion batteries and the first onshore container.

On the other hand, the support structure (including cathodic protection and cast-iron ballasts) will be built in a yard in Southeast Asia, as close as possible from San Bernardino.

Once the subparts of the turbine are built and tested in France, the elements will be shipped from Brest (France) to the local yard by cargo.

In parallel of the assembly, onshore works ought to be carried out in Capul for the landfall and prepare the grid connection with the installation of the onshore containers.

D. *Certification*

Standards dedicated to tidal stream power devices are under development by the classification and certification bodies DNV-GL, BUREAU VERITAS (BV) or IEC. Conception process, calculation methods, characterization and selection of the construction materials, fabrication process of D10 and commissioning were closely followed up and validated by BUREAU VERITAS, partner of Sabella D10 project, in order to define a frame of reference and identify the relevant tools and methods for the certification of the TISEC device. One point of focus is the certification of the tidal turbine power curve in real operating conditions [1], a work done jointly with BUREAU VERITAS as one of the first applications of the standard IEC 62600-200 *Electricity producing tidal energy converter – power performance assessment* [3] issued in 2013. As Sabella D10 project started before the IEC 62600-200 publication, some monitoring requirements were not anticipated so the D10 power curve could not be rigorously certified according to the standard during the first year of operation. However, SABELLA and BUREAU VERITAS have worked together for the interpretation of the technical specification, the exploitation of the measurements and the presentation of the results. Since then, ADCP measurements were obtained at points surrounding the support structure as required by IEC. This data will be completed with ADCP measurements when the turbine is installed back on the support structure, in order to obtain the final power curve certification.

BUREAU VERITAS will certify the conception and the construction of the D20 turbine based on a standard currently under development, after the publication in 2015 of a set of guidelines, NI 603 *Current and Tidal Turbines* [4], intended to help the development of TISEC devices.

E. *Installation and commissioning*

Thanks to the modular architecture of SABELLA's marine current turbine, the installation is three-fold: first the support structure is positioned on the seabed, then the ballast and finally the turbine is lowered and wedged onto the foundation. Once this is done, the export cable is installed, from each device to the landing point onshore and grid-connected to the onshore substation.

VI. TECHNICAL, ECONOMIC, SOCIAL AND ENVIRONMENTAL STAKES

A. *First tidal power plant in the Philippines and in ASEAN*

The San Bernardino ocean power project envisions to become a reference project in ASEAN, by demonstrating the viability of an insular energy model based on tidal power generation. Already tested in Europe with the integration of D10 in the energy mix of Ushant, this energy model can be duplicated in ASEAN, especially in the Philippines and Indonesia, archipelagic countries counting over 9,000 and 17,000 islands respectively. The San Bernardino ocean power plant will trigger an international market penetration of tidal stream power in these areas, where tidal energy is already cost-competitive with the existing power generation sources, mostly fossil-fuel solutions, provided that the tidal resource is sufficient.

B. *Decarbonization of Capul*

Capul is not connected to the main electrical network in Samar island, so Capul's independent grid has its own power production assets. Today, the 15,000 islanders are powered by a thermal power plant equipped with four diesel generators, consuming around 900 litres of fuel per day, so around 330,000 litres per year. The ocean power plant will come as a substitution to these polluting devices, saving 850 tCO_2 a year in average, without considering transport and logistic to Capul.

C. *Energy security and cost competitiveness*

As the island relies upon four ageing generators, with only two running at a time, failures leading to prolonged blackouts in the barangays happen on a regular basis. The tidal turbines will secure the energy supply of the island and two diesel gensets will be kept on site only as back up supply. Besides, the diesel power plant inherently depends on the fuel (and lubrication oil) supply coming from the main islands, either from Allen (Northern Samar) or Matnog (Sorsogon), thus power generation is conditioned to the availability of fuel supply and weather conditions suitable for navigation. Even if tidal is a "fit-and-forget" solution, the ocean power plant functions without requiring external supply. Moreover, contrary to diesel generators, tidal turbines are not subject to fuel price volatility. Based on the current velocity predictions and the techno-economical maintenance model, the generation costs of the ocean power plant can be assessed prior to the commissioning for the whole service life of the tidal turbines.

D. *Economic development*

Since the first quarter of 2017, power supply in Capul has been increased from 8 to 16 hours per day, from 9am to 1am. Electricity is a key driver in the development of a region, including economic growth and social welfare. First, the San Bernardino Ocean power project will increase the energy access for over 5,500 people in Capul, so all the islanders can be grid-connected. Second, the tidal power plant will secure a 24-hour service. Besides domestic use, it will provide a steady electricity source for critical services such as medical facilities and schools. Capul counts one hospital l and 17 health centres. Electrified health facilities will improve treatment of patients, enable better sanitation, permit longer storage of medicines and allow the investment in modern equipment. On the other hand, none of the 14 schools in Capul is electrified at the moment. Besides, a reliable 24-hour energy access would boost the local economy, starting with the fishing activities. For example, the Local Government Unit would consider the creation of a refrigeration plant for the storage of fishery products, which would allow the fishermen to store and export their products. The enhanced electricity access is also an opportunity to tackle the issue of limited stocks of drinking water, by developing a desalination plant. Finally, a continuous electricity access would reinforce the tourist attractiveness of the island, which has a real potential with environmental attractions and historical landmarks inherited from the 400-year Spanish presence, the American imprint and the Japanese experience. Thus, the pilot farm would open real new service opportunities leading to economic growth.

E. *Environmental and social acceptation*

The objective is to achieve the environmental integration of tidal stream turbines, a new type of construction at sea in the Philippine waters. Return on experience can be drawn from the D10 project in Ushant, which provides some insights regarding the potential impacts and the mitigating measures. Social acceptance is also critical for such pioneering projects. In view of the welfare and economic opportunities that the ocean project will bring, Mayor Isidro Bandal stated his being in favour of the ocean project in a support letter, provided in the Annexes of the application. Public consultations will be organized on a regular basis for the whole development phase and during the lifetime of the power plant.

F. *Large-scale commercial deployment*

The strong currents observed in San Bernardino Strait lead to an estimated potential of 500 MW. After the first phase of the project in Capul, the ocean power plant located in Capul pass can be scaled up in order to provide power to the inhabitants of Capul and San Antonio Islands. The concession area in Matnog pass also encompasses very energetic points, so another tidal power plant could be deployed there to supply the island of Calintaan and eventually major towns in the province of Sorsogon, like Matnog, which await economic development provided electricity becomes reliable.

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