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Pilot Project for Tidal Current Exploitation on the Huelva Coast (TidUtil)

A. Álvaro de la Cruz Álamo[1], B. Jesús Clavijo Camacho[1], C. José Antonio Hernández Torres[1], D. María Reyes Sánchez Herrera[1]

[1] Department of Electrical Engineering
E.T.S.I., Huelva University
Escuela Técnica Superior de Ingeniería - Campus de «El Carmen» - Avda. de las Fuerzas Armadas, s/n. 21007 Huelva.
959217555, alvaro.delacruz@didp.uhu.es

Abstract. This work addresses the progress and development status of the TidUtil project, which explores the viability of installing a tidal turbine in the Huelva estuary as a sustainable response to rising energy demands and fossil fuel dependency. Huelva's unique coastal geography and extensive wetlands offer a strategic setting for tidal stream energy. Unlike other renewables, tidal power provides a stable and predictable output based on semi-diurnal cycles. This project proposes the installation as a pilot plant to evaluate the integration of modern turbine technology within this specific maritime environment. By serving as a foundational prototype for future large-scale deployments, the project addresses critical technical constraints, such as material degradation due to alkaline submerged conditions and fluctuations in flow velocity during neap tides. The findings suggest that despite environmental and mechanical challenges, the Huelva estuary represents a significant untapped resource for diversifying the regional energy matrix through clean, predictable marine power.

Key words. Tidal energy, Distributed energy, hydrokinetic turbine, pilot plant, sustainable engineering.

1. Introduction

The global transition towards sustainable energy systems necessitates the diversification of the renewable energy matrix to mitigate reliance on fossil fuels [1]. Among emerging renewable sources, ocean energy represents a vast, largely untapped resource, with global annual potential estimates ranging from a conservative 337 GW to an optimistic 32 TW [2], [3]. Tidal stream energy, in particular, offers a highly predictable and stable power output governed by semi-diurnal astronomical cycles [4]. Furthermore, tidal stream turbines operate on principles similar to wind energy but benefit from the superior density of seawater (1025 kg/m³ compared to 1.25 kg/m³ for air) [5]. This physical advantage enables tidal installations to achieve comparable power outputs at much lower flow velocities, potentially generating up to four times more energy per square meter annually [6].
The Gulf of Cádiz, and specifically the Huelva estuary, possesses a unique coastal geography and extensive wetlands that provide a strategic setting for tidal stream energy exploitation. Historically, this region has demonstrated a long-standing tradition of harnessing marine resources; during the 17th and 18th centuries, tidal mills such as the "Molino del Pintado" successfully utilized the area's tidal range to power local industries, representing an early paradigm of sustainable coastal engineering [7].
Despite recent advancements in marine renewable energy technologies, the majority of research and commercial implementation has focused on large-scale infrastructures designed for open ocean waters or massive current environments [8], [9]. While these large installations have conclusively demonstrated the technical viability and extraction capacity of hydrokinetic energy, there is a notable gap in the literature and industry regarding the development of systems geared towards micro-generation [10]. Currently, there is a lack of technologies adapted to operate efficiently on a small scale in more restrictive environments such as estuaries or shallow water channels where flow velocities are variable or fall below 1 m/s during neap tides. Although recent research is beginning to explore the development of new prototypes and floating hydrokinetic platforms [11], [12], the empirical validation of these devices under real and complex environmental conditions remains a significant challenge. It is precisely within this technological gap of micro-generation that the TidUtil project gains its primary relevance.
To address these technical constraints, the TidUtil project proposes the installation of a pilot plant to evaluate the integration of modern hydrokinetic turbine technology within the maritime environment of the Huelva coast. The experimental setup features a cross-flow tidal turbine integrated into a modular floating platform, ensuring buoyancy and stability via high-density polyethylene (HDPE) pontoons. This configuration facilitates maintenance accessibility and adapts to the significant tidal-range fluctuations characteristic of the estuary. The project is structured into five strategic phases: site selection, energy sizing, equipment acquisition and installation, adjustment and adaptation, and final experimental testing. Currently in its fourth phase, the initiative focuses on commissioning the system and

resolving the inherent technical challenges of pioneering maritime deployments.
The primary objective of the TidUtil project is to establish this pilot plant as a technological benchmark and a reference framework for future tidal energy installations in the region. Specifically, this work aims to: 1) conduct a technological validation of the cross-flow turbine's operational performance in a real estuarine environment; 2) achieve operational optimization by identifying and mitigating technical challenges related to salinity, alkalinity, and flow velocity fluctuations ; and 3) perform a scalability assessment by providing empirical data that facilitates the future deployment of larger-scale tidal farms along the Gulf of Cádiz.

2. Technical Description

A. Modular floating platform

Unlike fixed-bottom tidal structures, the TidUtil platform (Fig. 1) utilizes a floating configuration. The buoyancy system consists of high-density polyethylene (HDPE) pontoons, chosen for their resistance to the high alkalinity and salinity of the estuarine environment. This modular design reduces installation costs and facilitates maintenance operations without the need for heavy-lifting vessels. The platform is moored at the Marina del Odiel (Huelva).

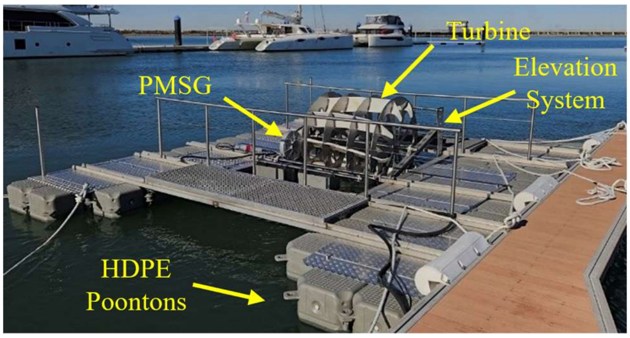

Fig.1. General view of the TidUtil floating platform moored at the Marina del Odiel.

B. Turbine characteristics

The core of the kinetic energy conversion system is a cross-flow hydrokinetic turbine with a horizontal axis, developed by Kliux Energies (Fig. 2) (Table I). The turbine design represents a technological evolution from Kliux's original vertical-axis wind turbine platform, adapted for hydrodynamic operation through a geometric transition to a horizontal-axis rotor operating under partial immersion (paddle-wheel logic).
The turbine features a rotor diameter of 1.40 m and a blade width of 1.60 m.. Figure 3 shows the theoretical power curves of the system across the expected flow velocity range, illustrating the available hydraulic power and the estimated electrical output for both a conservative (Cp = 0.10) and an optimistic (Cp = 0.22) scenario.

Fig.2. Kliux cross-flow hydrokinetic turbine: rotor detail (left) and blade geometry (right).

C. Electrical configuration

The electrical subsystem comprises the full power conversion chain from the generator to the grid connection point. The rotor drives a Greef GDG-450 permanent magnet generator (PMG), rated at 1 kW / 80 RPM / 220 V, through a 1:3 belt-driven gearbox.
The power electronics are housed in a technical room at the marina. The PMG output feeds a braking resistor for emergency stopping, followed by a Greef GT PCTC controller (5 kW) with MPPT tracking. The controller output connects to a Deye SUN-12K-SG04LP3-EU hybrid inverter interfaced with a Pylontech Force L3 battery bank, supporting grid-connected injection, battery storage, and islanded microgrid operation. An OpenZmeter smart meter at the point of connection records per-phase voltage, current, power, frequency, THD, and power factor.

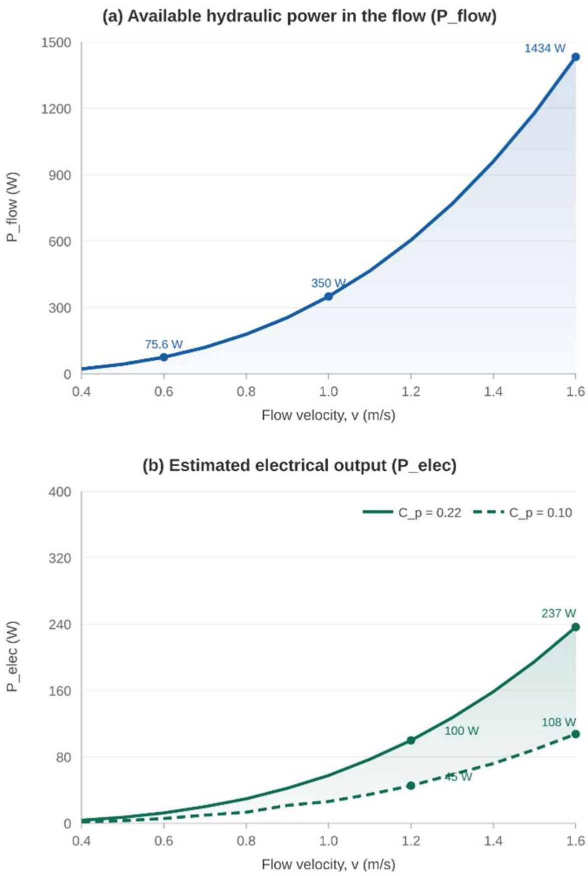

Fig.3. Power curves of the tidal turbine.

Table I. Technical specifications of the TidUtil hydrokinetic turbine and power conversion system.

Turbine type	Cross-flow, horizontal axis, partial immersion
Rotor diameter / blade width	1.40 m / 1.60 m
Effective submerged area (A_{ef})	0.67–0.70 m²
Design flow velocity range	0.4–1.6 m/s
Power coefficient (C_p) / efficiency (η)	0.10–0.22 / ≈ 0.75
Transmission	Belt-driven, ratio 1:3
Generator	PMG, 1 kW nominal @ 80 RPM
Power electronics	Greef controller + Deye hybrid inverter
Electrical output @ 1.2 m/s	≈ 87 W AC (PMG @ 36.8 RPM)
Buoyancy system	HDPE pontoons

3. Experimental Setup and Feasibility Assessment

The feasibility assessment of the TidUtil project relies not on theoretical simulations alone but on converting the platform itself into a floating laboratory capable of real-time data acquisition. This section describes the testbed configuration, the hydrodynamic resource characterization methodology, the electromechanical and environmental monitoring instrumentation, and the IoT-based telemetry architecture.

3.1. Estuarine Testbed Configuration

The TidUtil platform is moored at the Marina del Odiel, located in the Huelva estuary at the mouth of the Odiel river. This site was selected based on several criteria: adequate channel depth (ensuring the turbine rotor operates at the optimal submersion depth throughout the tidal cycle), representative tidal current velocities, proximity to the University of Huelva for logistical support, and access to docking infrastructure that facilitates routine inspection and maintenance.

The Huelva estuary is classified as a mesotidal system with a semi-diurnal tidal regime. The tidal range varies from 0.70 m during extreme neap tides to 3.85 m during extreme spring tides. This large variation in water level is a primary justification for the floating platform concept, as a fixed-bottom structure would experience significant changes in submersion depth that would compromise turbine performance.

3.2. Hydrodynamic Resource Characterization

The tidal current resource at the deployment site has been characterized through a dedicated measurement campaign using an Acoustic Doppler Current Profiler (ADCP) deployed at the Marina del Odiel mooring point. The instrument recorded flow velocity at multiple depths over a complete spring–neap tidal cycle, with a sampling interval of 10 minutes. Figure 4 presents the time series of water velocity at 1.5 m depth, which was identified as the depth of maximum current intensity and therefore the most relevant for optimizing rotor immersion.

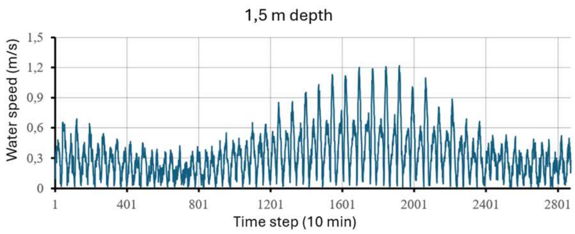

Fig.4. Time series of water velocity at 1.5 m depth recorded by ADCP at the deployment site over a complete spring–neap cycle (10 min sampling interval).

The measured data confirm a bidirectional (ebb and flood) flow pattern consistent with the semi-diurnal tidal regime of the Huelva estuary. Flow velocities range from approximately 0.2 m/s during neap periods to peaks above 1.2 m/s during spring tides, with the ebb (outgoing) current being consistently stronger than the flood. The semi-diurnal periodicity is clearly visible, as is the spring–neap modulation over the record length. These measurements validate the historical hydrographic data from the Huelva.

3.3. IoT-Based Remote Monitoring and Data Telemetry

The TidUtil platform incorporates a multi-layered remote monitoring (Fig. 5) system that enables continuous supervision of the installation without requiring on-site visits. Three complementary devices provide different levels of detail. The Greef GT PCTC controller reports the fundamental generation variables in real time, including DC bus voltage and rotor speed, and maintains direct communication with the Deye inverter to coordinate system operation. The Deye SUN-12K-SG04LP3-EU inverter offers cloud-based monitoring through its proprietary platform (Deye Cloud), accessible via mobile application, providing instantaneous and historical production data, self-consumption figures, and power exchanged with the grid. The OpenZmeter smart meter,

installed between the inverter and the grid connection point, delivers the most comprehensive electrical characterization: per-phase RMS voltage, current and power, grid frequency, individual and total harmonic distortion (THD), power factor, and waveform visualization. All measurements are stored and exportable in CSV format for offline analysis. A webcam complements the instrumentation by providing real-time visual supervision of the turbine and platform status through a dedicated web application.
All communicating devices are connected to the internet through a network switch installed in the technical room, using the marina's WiFi infrastructure.

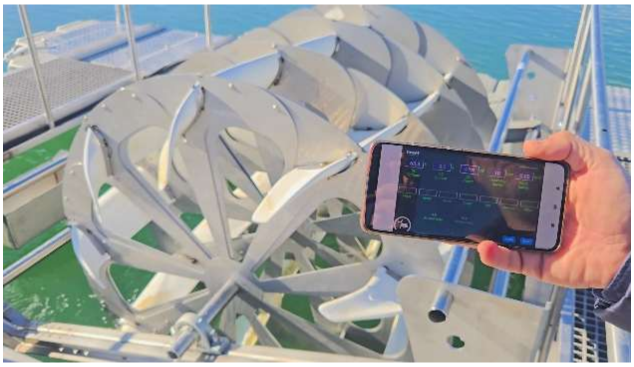

Fig. 5. IoT-based remote monitoring architecture: Greef controller interface and on-site instrumentation panel.

4. Preliminary Findings and Expected Performance

4.1. Structural Resilience and Passive Commissioning

Following several weeks of continuous deployment at the Marina del Odiel, the TidUtil platform has provided encouraging evidence of structural resilience. The HDPE pontoons have maintained the designed draft and buoyancy characteristics throughout multiple spring–neap tidal cycles, withstanding the dynamic loading imposed by bidirectional currents and wind-driven waves within the estuary. No deformation, cracking, or loss of buoyancy has been observed in the pontoon system.

Fig. 6. Condition of the steel frame and sacrificial anodes after several weeks of continuous estuarine deployment.

The metallic frame and turbine mounting structure have likewise shown satisfactory structural behaviour (Fig. 6). Preliminary visual inspections indicate that the surface treatments applied to the steel components are performing adequately against the saline and alkaline conditions of the estuary, although quantitative corrosion rate measurements will require a longer observation period. The turbine blades show no signs of fouling or material degradation at this early stage of deployment (Fig. 7).

Fig. 7. Turbine blade surfaces after sustained operation, showing absence of biofouling due to continuous rotor motion.

Critically, the Kliux rotor has been observed to respond consistently to tidal current forcing during both ebb and flood phases, confirming the turbine's omnidirectional capability and its ability to self-start at the low flow velocities characteristic of the estuarine environment. This qualitative observation validates the fundamental design premise of the partially immersed cross-flow configuration for low-velocity tidal applications.

4.3. Theoretical Power Projections

Using the technical specifications of the turbine and the characterised flow velocity range, theoretical power projections have been calculated to provide the quantitative performance estimates required for feasibility assessment. Table II summarises the key operating points across the expected velocity range.

Table II. Theoretical power projections across the expected flow velocity range (Cp = 0.10–0.22, η = 0.75).

Flow Velocity (m/s)	Pflow (W)	RPM_PMG	Pelectrical (W)	Condition
0.4	22.4	12.3	≈3–5	Cut-in (neap tide)
0.6	75.6	18.4	≈10–18	Low flow
0.8	179.2	24.6	≈18–35	Conservative baseline
1.0	350.0	30.7	≈50–70	Moderate flow
1.2	604.8	36.8	≈87–120	Typical conditions
1.6	1433.6	49.1	≈215–280	Spring tide peak

The electrical power estimates in Table I assume a Cp range of 0.10–0.22 and a global system efficiency η of 0.75, applied to the hydraulic power available in the flow. These projections confirm that the dominant performance constraint is the available hydrodynamic resource in the estuary, not the turbine's mechanical or electrical design capacity.

Simplified annual energy production (AEP) estimates have been calculated for two scenarios. A conservative scenario, assuming a mean flow velocity of 0.8 m/s (representative of neap-dominated periods), yields approximately 158 kWh/year. A validation scenario at 1.2 m/s mean velocity produces approximately 760 kWh/year. These figures serve as theoretical reference values for order-of-magnitude assessment and will be refined as measured flow velocity data becomes available from the planned ADCP campaign.

5. Conclusions

The successful installation and initial commissioning of the TidUtil floating platform at the Marina del Odiel establishes a precedent for tidal current energy exploitation on the Huelva coast. The following principal conclusions can be drawn from this work:

First, the integration of Kliux cross-flow hydrokinetic turbine technology with HDPE pontoon-based flotation and IoT remote monitoring constitutes a technically viable solution for micro-generation in estuarine environments subject to high salinity, alkalinity, and large tidal range variations.

Second, the theoretical analysis, supported by initial operational observations, indicates that the platform can deliver a useful electrical output of 50–150 W under typical estuarine flow conditions (1.0–1.2 m/s), with an estimated annual energy production between 158 and 760 kWh depending on flow scenario. The power coefficient Cp of 0.10–0.22 and global efficiency of 0.75 are consistent with the drag-based, partially immersed operating principle of the turbine.

Third, the IoT-based telemetry system has proven capable of reliable continuous data transmission from the maritime environment, enabling real-time remote monitoring, automated alerts, and cloud-based data visualization that significantly reduce the operational burden of maintaining an unattended offshore pilot plant.

Finally, the TidUtil concept demonstrates strong replicability potential. Marinas and recreational ports located in tidal estuaries along the Spanish and European coastlines share the same fundamental conditions exploited in this project: predictable bidirectional currents, existing mooring infrastructure, grid connection points in close proximity, and sheltered waters that simplify installation and maintenance logistics. The modular and floating nature of the platform eliminates the need for civil works or seabed intervention, enabling deployment by standard marina equipment within days. This positions tidal micro-generation as a realistic distributed energy solution.

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