Position keeping costs of floating offshore platforms for marine renewable energies

Laura Castro-Santos, Sara Ferreño González, Vicente Díaz-Casas, José Ángel Fraguela Formoso

Escuela Politécnica Superior, Universidad de A Coruña, C/Mendizábal s/n, 15403 Ferrol, A Coruña (España)

Teléfono +34981337400; Fax: +34981337410;

laura.castro.santos@udc.es; sara.ferreno@udc.es; vicente.diaz.casas@udc.es; jafraguela@udc.es.

ABSTRACT.

This article defines a method to calculate the position keeping (mooring and anchoring) costs of floating offshore platforms, which can be used to determine the economic viability of a marine renewable energies project. The example will define the most common floating offshore wind platforms (spar, semisubmersible and TLP), their mooring connection (tensioned or non-tensioned) and the type of anchor used. The proposed methodology will be developed using the life-cycle phases of each component considered. Furthermore, the method has been carried out for a floating offshore wind farm located in the North-West of Spain (Galicia region). Results can help to decide what the best option is in economic terms.

Key words. Floating renewable energy, offshore mooring, anchoring, position keeping

1. INTRODUCTION

Offshore wind energy will be developed in next years in order to achieve European Union objectives [1]. However, there are places where depth is very high, so fixed offshore wind structures (monopile, tripod, etc.) cannot be installed. In this context, floating offshore energy will take part in offshore market.

However, one of the most important differences between fixed and floating substructures are mooring and anchoring systems.

In this sense, the aim of this article is defining a methodology which can evaluate the position keeping costs of floating offshore platforms for marine renewable energies. For this purpose several installation, preventive maintenance and decommissioning models of floating offshore wind devices will be considered.

2. METHODOLOGY

2.1. Total cost

The life cycle phases ($\boldsymbol{i}$) of a product will be the base of the methodology proposed [2] [3]: definition, design, manufacturing, installation, exploitation and dismantling, as Fig. 1 shows:

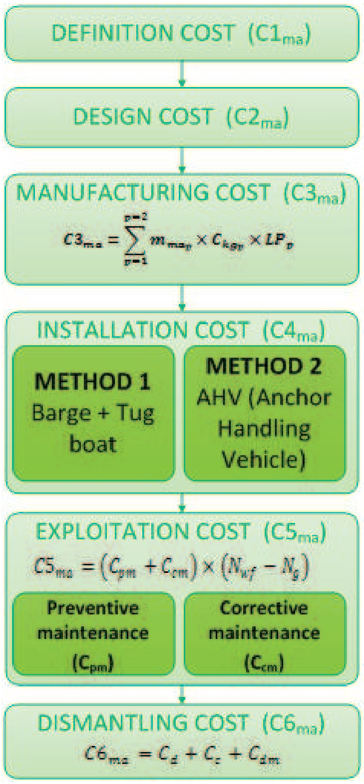

Fig. 1. Life-cycle phases of the position keeping.

Regarding this consideration, total cost of a mooring and anchoring system ($\boldsymbol{C_{ma}}$) will be as follows:

$$C_{ma} = \sum_{i=1}^{i=6} Ci_{ma} \quad (1)$$

2.2. Phase 3 cost

Manufacturing costs ($\boldsymbol{C3_{ma}}$) are calculated taking into account the cost in €/kg ($\boldsymbol{C_{kg}}$) [4] of mooring (p=1) [5] and anchoring (p=2) and their respective mass ($\boldsymbol{m_{ma}}$):

$$\boldsymbol{C3_{ma}} = \sum_{p=1}^{p=2} \boldsymbol{m_{ma_p}} \times \boldsymbol{C_{kg_p}} \times \boldsymbol{LP_p} \quad (2)$$

In this sense, mooring and anchoring [6] devices will be dimensioned considering they are satisfying the requirements related to acting forces (wind [7], waves [8] and currents) [9] [10].

2.3. Phase 4 cost

Regarding installation costs ($\boldsymbol{C4_{ma}}$) of mooring and anchoring, two different methodologies will be considered [11]. Method 1 employs a barge and a tugboat. Method 2 requires a specific vessel called AHV (Anchor Handling Vehicle). Moreover, it should be noted that in the case of anchors, AHV vessel dropped directly anchor, completing the installation process. This technique avoids the use of subsea equipment, but makes difficult the placement of the anchor at the desired location. Furthermore, suction piles are cylindrical boxes which are embedded in seabed by suction. These are lowered to the seabed and then suction is applied by a valve, which is located at its top. This installation process requires the use of subsea pumps and, sometimes, divers.

Cost calculation for Method 1 and Method 2 is:

Method 1	Method 2	
$C4_{ma} = \left(C_b + C_{tb} + C_{DL} + C_{pd}\right) \times \left(\frac{N_{anchors}}{T_{instb}}\right)$	$\boldsymbol{C4_{ma}} = \left(\boldsymbol{C_{AHV}} + \boldsymbol{C_{DL}} + \boldsymbol{C_{pd}}\right) \times \left(\frac{\boldsymbol{N_{anchors}}}{\boldsymbol{T_{instAHV}}}\right)$	(3)

Being:

- C_b: barge cost (€/day)

- C_{tb}: tugboat cost (€/day)
- C_{DL}: direct labour cost (€/day)
- C_{pd}: pumps and divers cost (€/day)
- $N_{anchors} = NWT \times LP$: number of anchors (anchors)
- T_{instb}: barge installation time (anchors/day)
- NWT: number of wind turbines (wind turbines)
- LP: number of mooring lines per platform (lines/platform)
- $\boldsymbol{C_{AHV}}$: AHV cost (€/day)
- $\boldsymbol{T_{instAHV}}$: AHV installation time (anchors/day)

2.4. Phase 5 cost

According exploitation cost ($\boldsymbol{C5_{ma}}$), two different issues will be considered [12]: preventive maintenance ($\boldsymbol{C_{pm}}$) and corrective maintenance ($\boldsymbol{C_{cm}}$). Furthermore, we should take into consideration the fact that corrective costs will differ depending on the year of the life cycle ($\boldsymbol{N_{wf}}$), because there is a guarantee stage ($\boldsymbol{N_g}$):

$$C5_{ma} = \left(C_{pm} + C_{cm}\right) \times \left(N_{wf} - N_g\right) \quad (4)$$

The goal of preventive maintenance is to replace and renew components following an established programme: periodic inspections of equipment, cleaning, etc. On the other hand, the corrective maintenance is not programmed, taking place after the occurrence of a fault in the system [12].

Costs of preventive and corrective maintenance are given by:

Preventive maintenance	Corrective maintenance
$C_{pm} = CPM_{TRANSP} + \sum_{p=1}^{p=2} CPM_{MAT_p} + \sum_{p=1}^{p=2} CPM_{DL_p}$	$C_{cm} = \sum_{p=1}^{p=2} P_{f_p} \times (CCM_{DL_p} + CCM_{TRANSP_p} + CCM_{MAT_p})$

(5)

Being:

- CPM_{TRANSP}: cost of transport for preventive maintenance
- CPM_{MAT_p}: cost of materials for preventive maintenance
- CPM_{DL_p}: cost of direct labour for preventive maintenance
- P_{f_p}: failure probability, which will consider the forces acting on the floating platform and the strength of the systems using Montecarlo Method [13]
- CCM_{DL_p}: cost of direct labour for corrective maintenance
- CCM_{TRANSP_p}: cost of transport for corrective maintenance
- CCM_{MAT_p}: cost of materials for corrective maintenance

There are several preventive maintenance strategies: Onshore (without permanent accommodation): helicopter (M1), hiring Field Support Vessel (FSV) (M2) or buy a FSV (M3); Offshore (with permanent accommodation): buying FSV (M4).

2.5. Phase 6 cost

The floating offshore wind farm must be dismantled and removed for repowering [14] or only ending the activity. Firstly, wind farm will be disassembled using specialized vessels. Once the material is onshore, it may be sold as junk, receiving income (which will be counted as negative cost), or deposited in some specific place, paying for it.

Therefore, the cost of dismantling ($\boldsymbol{C6_{ma}}$) is composed by the cost of decommissioning moorings and anchors ($\boldsymbol{C_d}$), the cost of cleaning the affected area ($\boldsymbol{C_c}$) and the cost of disposing the materials ($\boldsymbol{C_{dm}}$) [15]:

$$C6_{ma} = C_d + C_c + C_{dm} \quad (8)$$

3. CONSIDERED MODELS

Three platforms will be considered: semisubmersible (Model A), Tensioned Leg Platform (TLP) (Model B) and spar (Model C). The number of lines per platform (LP) for each of these platforms is 6, 8 and 3 respectively [16]. Moreover, mooring disposition systems could be: transitional no tensioned systems (1), slack no tensioned system (2), Tensioned Leg Platform (TLP) tensioned (90º) (3) or Taut Leg Buoy (TLB) tensioned (45º) (4), as we can see in Fig. 2:

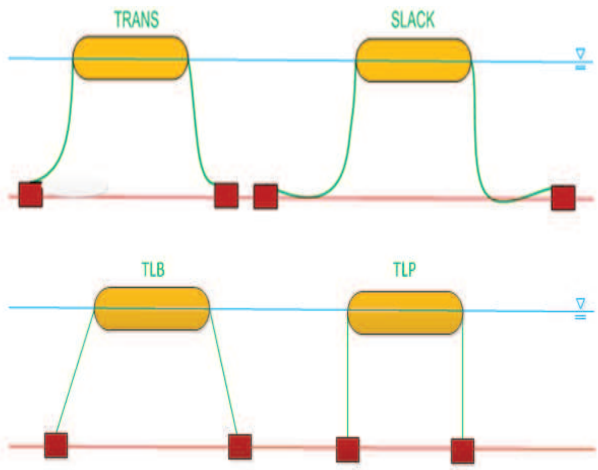

Fig. 2. Mooring models

Regarding mooring materials we will consider three cases: chain (Ch), cable (Ca) and synthetic fibre (polyester) (Fi).
Moreover, cohesive (CS) and no cohesive soils (NCS) will be studied.

Finally and regarding anchoring, four different alternatives will be taken into account: drag embedment anchor (De) [17], suction pile (Sp) [18], gravity anchor (Ga) and plate anchor (Pa).

However, platform TLP with no tensioned mooring (slack or transitional) will be rejected, considering its own definition, which implies tension. Furthermore, drag embedment anchor does not allow vertical forces and plate anchor does not accept horizontal forces [19].

4. RESULTS

Results have been obtained taking into account that floating offshore wind farm is located in Galicia (North-West of Spain), which will condition, through environmental forces applied, anchoring and mooring dimensions.

As we can see in Fig. 3, results for manufacturing costs of mooring indicate that most expensive mooring is Model B-tensioned (90º)-chain with a cost of 28,915,174 €. Moreover, the cheapest one is Model C-tensioned (45º)-fibre with a value of 505,867 €.

Regarding anchoring, the cheapest anchor is plate anchor with costs between 793,800 for Model A and 2,721,600 € for Model B. On the other hand, the most expensive anchor is suction pile with values between 4,596,218 and 9,906,676 €.

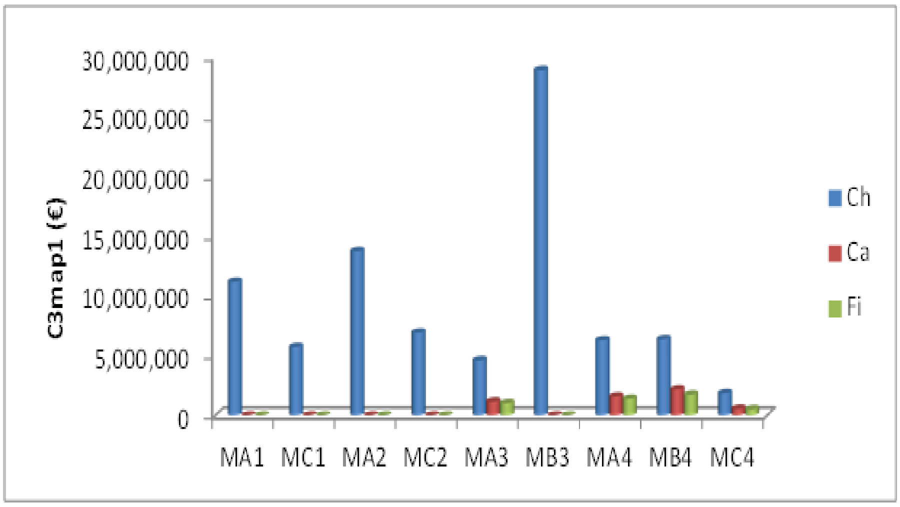

Fig. 3. Manufacturing mooring cost

Installation costs depend on the type of anchor considered, because their installation method is different. In this sense, drag embedment anchors, gravity anchors and plate anchors do not need pumps and divers, so their cost will be less than suction piles, as we can see in Fig. 5.

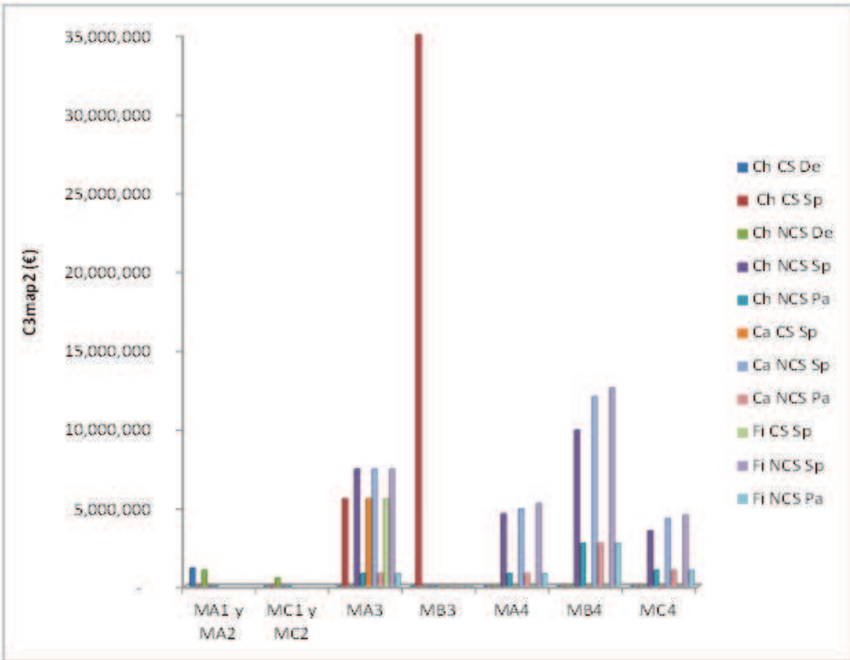

Fig. 4. Manufacturing anchoring cost of tensioned and non tensioned systems

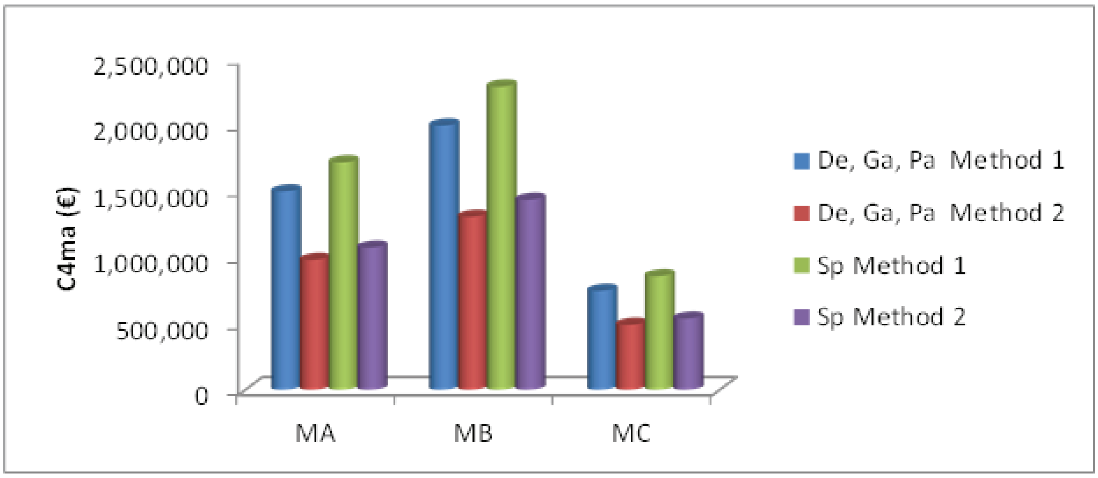

Fig. 5. Installation costs for drag embedment anchors, gravity anchors and plate anchors

Method 2 based on the use of AHV vessel is cheaper than Method 1, which combines barge and tugboat. In fact, the difference in terms of costs is around 600,000- 700,000 €.

According preventive maintenance, helicopter (M1) is the cheapest preventive maintenance system, with value of 388,266 €, as we can see in Fig. 6. On the other hand, the most expensive maintenance method is one which involves buying a FSV vessel (M3), with values up to 1,235,275 €. This result depends a lot on the distance to shore.

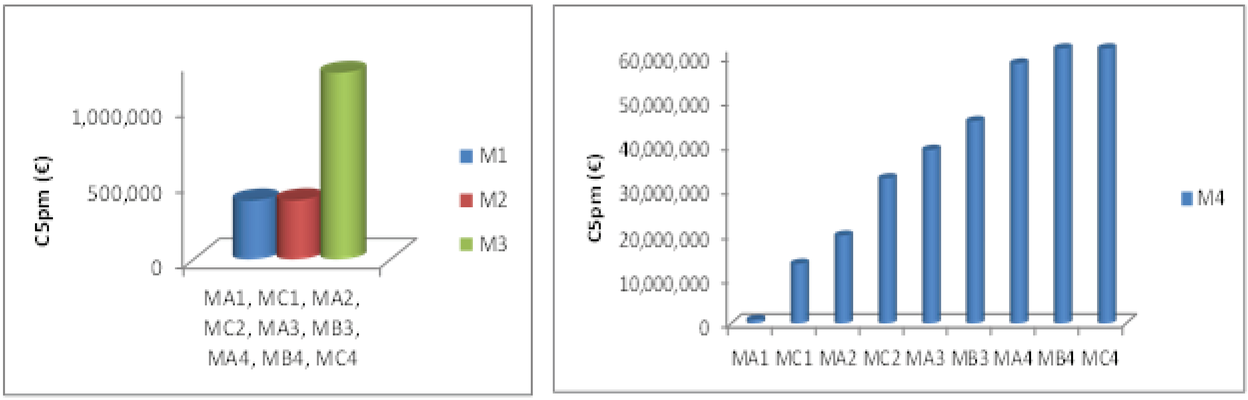

Fig. 6. Preventive maintenance costs for non tensioned and tensioned platforms

Otherwise, corrective maintenance costs related to mooring systems differ from 392.48 in Model A with transitional mooring to 125,997.50 € in Model C with slack mooring, as we can see in Fig. 7:

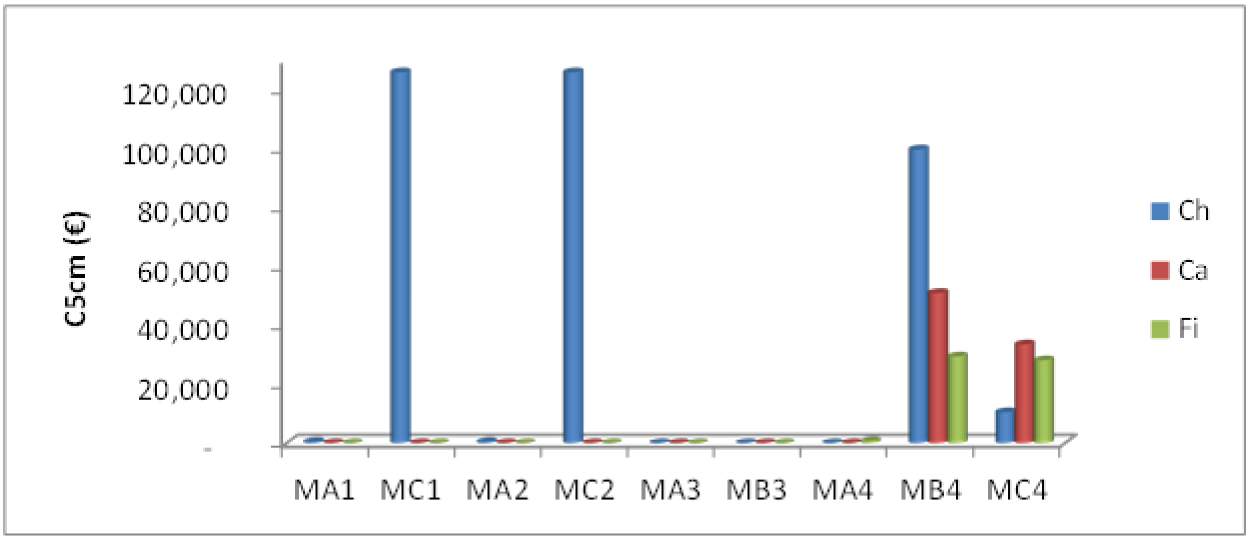

Fig. 7. Corrective maintenance costs for non tensioned and tensioned platforms

On the other hand, most of corrective maintenance costs related to anchoring systems are too much reduced because the failure probability is low (high security coefficients have been considered). In fact, they have values from 955.40 to 48,946.54 €.

According dismantling, we have three different costs: decommissioning, cleaning and disposing materials. Considering decommissioning, there are some differences in costs depend on the type of anchor used, as we can see in Fig. 8. Moreover, cleaning costs will be 200,000 €, being common for the entire wind farm, and disposing materials cost is 213,239 €.

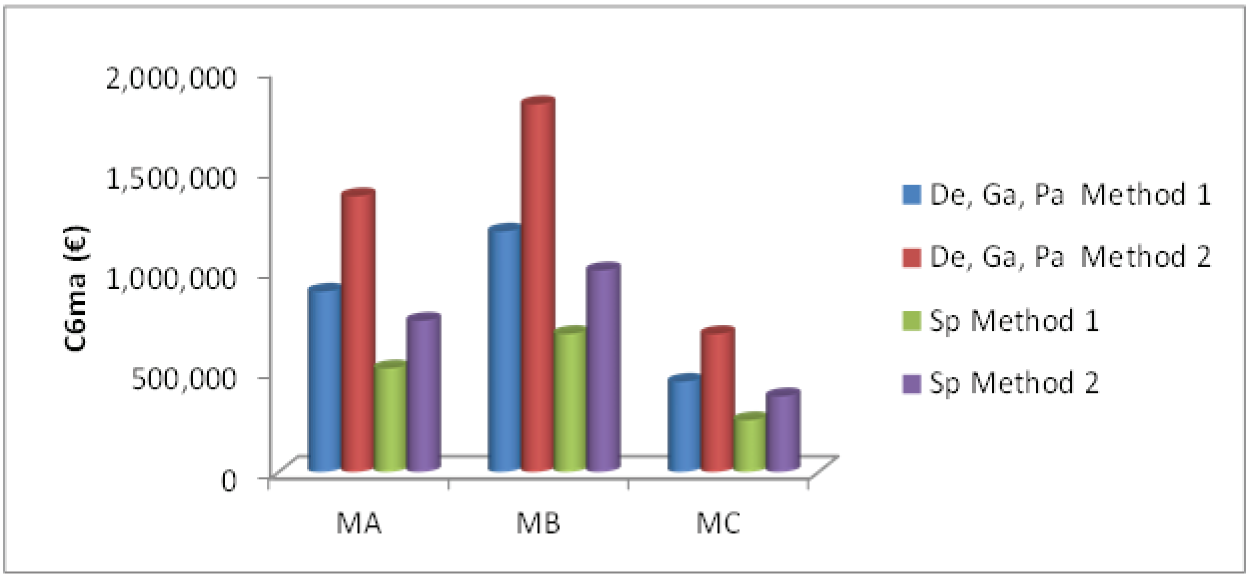

Fig. 8. Decommisioning costs for drag embedment anchors, suction piles, gravity anchors and plate anchors

5. CONCLUSION

The phases of the life cycle cost of the position keeping of a floating offshore wind farm have been taken into account: manufacturing, installation, exploitation and dismantling. They have been considered to develop each of the cost of a floating offshore platform.

Regarding to results, synthetic fibre and plate anchor are, in economic terms, the best mooring and anchoring systems. Otherwise, considering installation process, most economic method is using an AHV vessel. Nevertheless, in terms of dismantling using a cargo barge and a tugboat will be the best alternative.

Concerning maintenance, use helicopter of preventive purposes will be the best option.

The method described can help to determine the economic viability of a marine renewable energy project in the future.

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