A feeding management system: The integration of a renewable energy sources system with aquaculture

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Abstract: - Today, aquaculture products account for more than fifty percent (50%) of all fisheries products consumed on a Global scale. Fish feed accounts for more than 60% of all costs of aquaculture farms and successful monitoring of fish feed consumption is key to such companies’ profitability. This paper presents the development of a Renewable Energy System (RES) to be mounted on offshore aquaculture cages, enabling remote fish feed monitoring. Such systems are vital for aquaculture industry proliferation further away from coast.

Key-Words: - Renewable Energy Systems, Offshore Aquaculture, Fish Feed, Structural Integrity, Food Sustainability, Fisheries.

1 Introduction

It is widely accepted that approximately 60% of all operating costs in aquaculture industry account for fish-feed; therefore high quality feeding management is essential for all fish-farmers [1]. The average price of the ingredients commonly used in fish-feed jumped between 20 and 92 percent from June 2007 to June 2008 [2]. According to the same authors, fish feed prices vary from a few hundred dollars a ton to more than 1,000 USD a ton, depending on the species being fed. Aquaculture fish feed is composed of a collection of abundant ingredients such as soybean, corn, fishmeal, fish oil, rice and wheat. However, since 2005 prices of these commodities have soared — prices of wheat, rice and fish oil have increased 180, 225 and 284 percent, respectively. Thus, it is essential to monitor when to feed the fish in a sea cage in relevance to environmental conditions in order to reduce the costs.

Although many European Nations’ policies encourage the increase of the aquaculture sector, the competing use of shallow coastal waters for other industrial and sectorial uses, such as tourism and carbohydrates industry, prohibits substantial growth of the coastal aquaculture sector [3]. Therefore, the option of placing the aquaculture installations even further from shore, to offshore waters, it is considered as a solution. Nevertheless, this approach has a number of inherent technical and operational challenges.

One of those challenges is associated with the fish-feed and its enormous cost burden. Appropriate feeding times must ensure maximum utilization hence the lowest fish-feed loss. Additional costs within feeding operations must also be monitored such as the fuel consumption of boats. The distance that fish-feeding boats must now cover is greater thus, fuel costs are expected to increase therefore an appropriate feeding schedule must also be in place.

Minimizing fish-feed loss requires significant monitoring that must be set-up to collect relevant information on-site. As a result, substantial energy requirements are needed in a cost-effective way. Moreover, operational issues must also be tackled to ensure that core operations of the fish farm remain uninterrupted.

Renewable energy sources (RES) might have the answer, however, as discussed by [3, 4] cages
structural integrity, maintenance and repair operations and economic aspects, must be examined. Thus, this paper provides an overview of such an endeavor and describes how all aforementioned challenges are dealt with.

2 Case-study particulars
The aquaculture fish farm under study is located at the coast of Larnaca, at the Vasilikos bay area, north of Cyprus. The fish farm is situated around 1.2 km from shore and is composed out of 18 cages, grouped in 2 rows of 9 cages each (Fig. 1).

The farm’s rectangular shape is oriented in such a way that its narrow side is facing towards the predominant winds which come from the southwest (refer to Fig.1). The reared species are predominantly seabream (Dicentarchus labrax) and seabass (Sparus aurata). Fish-feed comes in form of pellets with a diameter ranging from 1.8 to 6 mm, depending of the fish age.

The cage arrangement is based on the surface grid arrays, see Fig. 2, made out of floating cages anchored on the seabed with ropes, rope rings, shackles, chains, buoys, concrete blocks, etc (a more detailed description can be found in [4]).

3 Problem: Fish-feed loss
As previously stated, fish-feed costs account for almost 60% of all costs in an aquaculture farm. Fish-feed loss during feeding times is an issue that aquaculture companies always try to overcome. However, because feeding must be performed every, or almost, every day, it is not as efficient as desired. This is due to environmental conditions variations associated either exclusively with the fish-population or with the sea’s conditions.

Another important factor that should be taken into account is the feeding frequency and control. Large quantities of uneaten fish-feed, in addition to feces, sink to the bottom beneath the cages, may have an unfavorable impact on the marine environment. The water quality will be affected, fish stock will be threatened and deleterious impacts will be created on the surrounding marine environment. This is because oxygen depletions may occur due to decomposition of accumulated waste material.

3.1 Environmental factors
Environmental factors are a broad category that encloses all parameters associated with an aquaculture farm that are a result of weather conditions and sea’s state. In the forthcoming subsections, the fish species-associated factors are presented followed by the general, sea-conditions, ones.

3.1.1 Fish population
According to [5], production in the aquatic farming industry is determined by the daily growth of the particular species. Growth in a tank or cage depends not only on the ration size, but also on multiple internal and external factors, such as density, temperature or fish social behavior, which makes the modeling not an easy task. To formulate and calibrate properly the functional determinants of growth for each species an estimation of the metabolic aspects of cultured fish is necessary.

Although the aquaculture environment is a complex system consisting of several water quality variables, only few of them play decisive role. The water temperature is an example of an environmental condition which affects production in offshore aquaculture. The observed variability of temperature across the year adds a risk component to farming decisions, which makes the theoretical predictions of bioenergetic models to depart from empirical findings [6].

Other critical species-related parameters are suspended solids and concentrations of dissolved oxygen, ammonia, nitrite, carbon dioxide and alkalinity. However, dissolved oxygen is the most important and critical parameter, requiring continuous monitoring in aquaculture production systems [7]. This is due to fact that fish aerobic metabolism requires dissolved oxygen [8].
3.1.2 Sea-related conditions
Feeding time must occur at times of sea calmness or relative calmness. Feeding must be performed each and every single day and only in extreme weather conditions, i.e. storms, feeding operations are interrupted. Usually the sea is described as calm when no high waves are present. Although this is true, there are other factors that must also be taken into account. Even in relative calm days, unseen environment parameters affect the amount of fish-feed loss.

Sea currents are perhaps the prominent “silent” parameter that aquaculture professionals monitor. It is possible for strong currents to exist without the coexistence of high waves and/or strong winds. Currents, in terms of depth of occurrence, speed and direction, even though are necessary for adequate water exchange and waste dispersion, need to be within defined values. Strong currents will apparently drift the feed pellets away from the cage before the fish have time to eat.

Similarly, and most obvious, is the wind profile during feeding times. If the prevailing wind speeds are high and have a direction that affect the fish cages, then as in the case of sea currents, the feed pellets will be blown away from the cage. Thus, it is useful to know the wind speed and wind direction “a priori” to avoid feeding at unfavorable conditions.

Other factors such as (a) water clarity and (b) day-length contribute in the fish-feed utilization. The former refers to the fact that during periods of poor water clarity, fish apparently had difficulty detecting pellets and therefore eat more poorly [9]. In terms of the latter, data concerning various aquaculture fish species show that the enhancement of growth performances under increased photoperiods were attributed to improved appetite, greater food intake and higher feed conversion efficiency as well as higher digestibility. [10,11]. However, both factors don’t really apply in this case since Cyprus has oligotrophic waters and the farms are semi-intensive aquaculture systems (intensive grow-out systems).

3.2 From coastal to offshore waters
Currently all aforesaid factors affect the amount of fish-feed lost during feeding. Nonetheless, the sea-related conditions, which affect the fish-feed loss the most, can be easily monitored through observation since the farm is located relatively close to shore as shown in Fig.1. In particular, the wind profile on-site can be extrapolated from onshore weather stations with minor deviations, whereas wave heights can also be seen from shore. Sea currents are known to be of low magnitude due to the shielded location of the farm, behind the Akrotiri peninsular.

However, as the aquaculture farm is sought to move further offshore these factors’ impact is expected to augment. The wind profiles no longer can be extrapolated based on onshore data, wave heights are directly correlated to those wind profiles and similarly, currents profiles are unknown. In simple words, offshore waters are a harsher environment and on-site, real-time monitoring is needed. Lastly, boat fuel consumption will also increase. Longer distances require more fuel not only for feeding but for all other daily operational activities, such as net inspection.

4 Solution: A feed management system powered by a RES system
A feed management system can help tackle the issue of lost fish-feed as it exists currently, but most importantly its foreseen deterioration that originates from the future offshore relocation of the farm. This system collects data for all aforementioned parameters through on-site deployed sensors and instruments and wirelessly transmits those to the on-shore base. From there the feeding operations are better organized according to integrated live data regarding the sea’s conditions and fish population’s status.

Similar commercial off-the-shelf systems exist from companies such as AKVA, as described by [3], yet those are mostly developed for near-shore aquaculture installations. This explains the fact why those systems have relatively high-energy requirements which does not constitute a problem since power grid connectivity in available or in the worst case, large generators can be deployed.

Yet in our case grid connectivity is prohibited due to the high cost that would occur if a power cable was to run from the farm to the coast. Likewise, large power generators cannot be safely deployed on-site. Consequently, a stand-alone RES system is designed to provide on-site autonomy.

4.1 Feed management system’s energy requirements
Sizing the RES system involves firstly selecting which instruments and sensors are to be deployed and then recording their energy requirements. Through consultation with the farm’s operations manager and its experienced divers, it is decided that the feed management system will be composed of a sea current profiler, a temperature and an oxygen sensor.
Recording each instrument’s power consumption comes next coupled with setting the system’s voltage. It is also important to include a system loss factor as well as selecting the autonomy days. Table 1 lists all deployed in-situ instruments and sensors, their power consumption and brief description.

Table 1 Power Consumption and Measurements

<table>
<thead>
<tr>
<th>Instrument/ Sensor</th>
<th>Power Consumption [mA]</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 RDCP600</td>
<td>1.29W [107.5]*</td>
<td>Current Doppler profiler</td>
</tr>
<tr>
<td>2 Temperature sensor</td>
<td>0.007W[0.6]*</td>
<td>Temperature sensor mounted on RDCP</td>
</tr>
<tr>
<td>3 Compass sensor</td>
<td>0.002W[0.18]*</td>
<td>Compass/ tilt mounted on RDCP</td>
</tr>
<tr>
<td>4 Real-time output</td>
<td>0.006W[0.513]</td>
<td>Software Dissolved oxygen sensor</td>
</tr>
<tr>
<td>5 RDO Pro Sensor</td>
<td>0.6W*</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>~2W</td>
<td></td>
</tr>
</tbody>
</table>

Measurements interval 10min = 480min per day = 8hrs
Measurement time 5min Autonomy days 1

* System voltage at 12V

As observed the total energy required is around 2 Watts for 8hrs per day. This transforms into 16Wh per day.

4.2 RES system’s components

Having in mind the autonomy day required in addition to the area of installation, the research team decided that it was best to explore the possibility of installing a stand-alone hybrid RES system, combining PV panels with a wind turbine. Several data as solar potential and wind potential were taken under consideration.

The hybrid system consists of polycrystalline PV panels, a small wind generator, a charge controller to protect the battery bank, and the energy storage system (batteries). The system operates at 12V DC, so no inverter is required. Both RE sources provide the energy produced to the battery bank. Additionally, for the research needs, two 12V power sensors were installed in order to measure the energy produced from the wind generator and the real energy consumed by the loads.

For the design of the PV system, several assumptions were made. Regarding the estimation of the electricity production from the PV modules, losses of around a 25% were considered. These losses concern reflectance effects, losses due to temperature, cable losses, etc.

More analytically, the power supply system mainly consists of two PV panels of 80Wp each, and a wind turbine of around 200W nominal power (at 12.5m/s). Two batteries of 90Ah capacity each and nominal voltage of 12V are included. The batteries are connected in parallel. Table 2 depicts all relevant information of the hybrid RES system.

Table 2 Technical characteristics

<table>
<thead>
<tr>
<th>Component</th>
<th>Characteristics-Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV-module SOLARWORLD</td>
<td>Type Polycrystalline</td>
</tr>
<tr>
<td>SW</td>
<td>Nominal power 80 Wp</td>
</tr>
<tr>
<td>L</td>
<td>5.08 A</td>
</tr>
<tr>
<td>Vr</td>
<td>17.9 V</td>
</tr>
<tr>
<td>Vs</td>
<td>21.7 V</td>
</tr>
<tr>
<td>Weight</td>
<td>8.4kg</td>
</tr>
<tr>
<td>Wind Turbine</td>
<td>Type Marine</td>
</tr>
<tr>
<td>Air Breeze - Marine</td>
<td>Wp 160-200W</td>
</tr>
<tr>
<td>Marine, Southwest</td>
<td>R.Speed 12.5 m/sec</td>
</tr>
<tr>
<td>Wind Power</td>
<td>Rotor diameter 1.17 m</td>
</tr>
<tr>
<td></td>
<td>Cut-in speed 2.68 m/sec</td>
</tr>
<tr>
<td></td>
<td>Weight 6 Kg</td>
</tr>
<tr>
<td>Batteries M27SMF</td>
<td>Type Sealed maintenance free,</td>
</tr>
<tr>
<td></td>
<td>deep cycle</td>
</tr>
<tr>
<td></td>
<td>Capacity 90 Ah</td>
</tr>
<tr>
<td></td>
<td>Nom.Voltage 12 V</td>
</tr>
<tr>
<td></td>
<td>Weight 35 Kg</td>
</tr>
<tr>
<td>Controller STECA PRS1010</td>
<td>Max Current 10 A</td>
</tr>
<tr>
<td></td>
<td>Nom. Voltage 12-24 V</td>
</tr>
</tbody>
</table>

The total weight of the hybrid system is around 95kg.

5 Operational factors

After sizing and selecting the RES system and its components, a design arrangement is developed. Hereby, focus is placed on the following construction requirements: accessibility, safety, integrity, stress minimization, and stability of the construction.

5.1 Environmental loads

Accurate identification of operational (daily) and extreme (storm events) environmental load cases for the design purposes helped develop more accurate models. Aquaculture cages are designed mainly to withstand forces and loads coming from (a) waves and (b) currents. In particular, the primary forcing mechanism cages and thus of paramount importance to quantify, are the stress levels expressed by the significant wave height (Hmo), and the dominant period (Tp), whereas in the case of currents, the velocity profiles. The latter are typically measured with Doppler instruments whereas the local wave climate can be either measured with deployed instrumentation or estimated from meteorological stations’ wind data, weather buoys and other sources.

Wind also highly influences the behaviour of a cage and an aquaculture farm, in general. The effects are dual. Firstly by inducing currents and waves and secondly, as loading force applied to the
components of the stand-alone RES system. This paper focuses on the latter. The following Table 3 depicts the magnitude of winds at the nearest shore location to the area of investigation, based on publicly available data (Cyprus Meteorological Service).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Daily magnitude</th>
<th>Extreme magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>15.5 m/s</td>
<td>31.4 m/s, 218°</td>
</tr>
</tbody>
</table>

5.2 Operational loads

Figure 3 illustrates the proposed design for the RES system installation on the aquaculture cage. Accessibility to the RES system and safety is provided by choosing a 3 m high galvanized steel pipe for the wind turbine to allow enough room for working staff to move safely on the cage. The proposed solution integrates all RES system’s components i.e., the wind turbine, the photovoltaic module, the batteries and the controller on a single pole of the aquaculture cage. As far as construction stability is concerned, a detailed presentation of the finite element analysis of the construction follows in the next paragraph.

The operational loads of the proposed design configuration, i.e. air resistance for the wind turbine and PV panel and operational torque of the wind turbine, were calculated for a maximum wind speed of 100 km/h and the extreme environmental case of a storm with wind speed of 200 km/h. The calculated forces are illustrated in Fig. 3.

5.3 Structural integrity

One of the major requirements for the installation of the RES system on the aquaculture cage is the structural integrity of the components made of different materials mainly structural steel and High Density Polyurethane (HDPE) [12,13]. Hereby, challenges are raised concerning the fixing of the RES system on the cage and the joining and assembly of the components with each other. The proposed assembly of the RES system with the aid of two main nodes: the base frame and the connecting frame. All the major components are connected with each other and, finally, fixed supported on the HDPE cage. The main connection points and fixtures are shown in Fig. 3 as suggested prior to installation.

Fig. 3: Proposed design configuration and estimated operational loads

5.4 Reliability and maintenance

A major aspect, which is studied in detail during the design phase, is the reliability and stability of components and fixtures of the RES system installation. The entire CAD assembly including the geometrical characteristics, material properties and contacts between all the structural components is analyzed by means of the finite element analysis with the aid of the software ANSYS Workbench. For this purpose, the operation loads as illustrated in Fig. 4 are considered for a linear elastic analysis in order to identify weaknesses, i.e. areas of high stress concentration or undesirable deformations. Figure 4 shows the calculated stress distribution and maximum deformation for a crucial wind speed of 100 km/h. The assembly proves bearable deformations (ca. 50 mm) and stress concentration (less than 250 MPa) on the wind turbine pipe proving that even for this extreme environmental conditions the safety of the construction is provided. A minor improvement, i.e. reinforcement through material thickness increase, is suggested and implemented for the connecting frame in the area of the connection with the HDPE cage component.

Additional calculations for the extreme environmental operational loads during storms with wind speeds of around 200 km/h conclude to unavoidable permanent damage of the RES assembly. In case such extreme environmental conditions are predicted we propose an immediate disassembly of the RES system and onshore transport. Finally, due to high corrosion and loosening danger of connections exposing to wet and salty environment in one hand and dynamic
loading (continuous cage movement and wind turbine rotation) in the other hand a frequent inspection of connections and sealants (battery storage box) is suggested.

![Stress distribution, von Mises criterion [MPa] Deformation [mm]](image)

Fig. 4: Structural results for RES system assembly

6 Conclusion

In a Global Society that passed the seven billion population mark, food sustainability proves to be a challenging task. Since 70% of the Earth is covered with water, aquaculture industry has the prospects to address this need, if several challenges are overcome. This paper presented the case of a RES application to be applied on offshore aquaculture sites to enable remote monitoring. Such solutions remain to be tested in harsh and demanding operating environments such as the open sea.

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