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FLOATING PHOTOVOLTAICS – TECHNOLOGICAL ISSUES, COST AND PRACTICAL IMPLICATIONS.

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ABSTRACT: In space constrained countries such as Malta it is difficult to envision large scale PV farms on land due to the high cost and lack of availability of large stretches of suitable land. It is therefore natural to try to venture offshore as has happened elsewhere with wind-farms. Some of the challenges – higher communication costs, corrosive effects of the sea water, long term survivability – are the same. However sea-borne PVs have an edge when it comes to cost as their deployment would be logistically simpler than the massive wind turbines. They would also be less visible from shore and therefore less likely to be opposed on aesthetic grounds. The balance of system costs for an offshore system provides some advantages and some disadvantages when compared to a land-based system however it is believed that the overall cost could be similar to or even lower especially if special panels are developed for offshore use and since no expensive land-leasing would be involved. While most of the systems reviewed are on ponds some of the adopted solutions could also work in open sea and while challenging, other problems such as rough seas and biological fouling should be surmountable.

Keywords: PV, photovoltaic, floating, offshore

1 INTRODUCTION

Why even consider a floating Photovoltaic (PV) system? The simple answer is land availability. As shown below, most of the (very few) existing systems mounted on water were conceived because there was a pond or lake close to the area where the PV system was required. Installing the system on the body of water saved valuable use of real estate elsewhere. The not so obvious answer could be cost – while instinctively we would assume that an offshore system must be more expensive, under certain circumstances it might even be cheaper than a land-based systems – since the cost of land can add significantly to the balance of system costs of a large PV system.

There are currently no large scale PV systems on water, and in many cases it is cheaper and simpler to install such systems on land. However, in land constrained countries or densely populated coastal regions sufficient space for megawatt scale system might simply not be available. It might also be more advantageous to place the PV system on the water due to proximity to high consumption on the coast and scarcity of large open (and available) fields.

This is clearly the case in Malta. The largest system currently installed is the 840kWp system at Baxter Inc. A few larger systems are planned on unused quarries and large roofs but so far indications are that the MEPA (Malta Environment and Planning Authority) policy, which should be out shortly, will prohibit PV farms on ODZ land (outside development zone). This will limit PV farms to rooftops, unused quarries and land within building zones. While there are encouraging signs that many unused quarry and large roof owners will consider installing PV farms, it is unlikely that many would consider such installations in building zones due to the high value of the land.

On the other hand Malta has territorial waters that extend 9.65km out from the coast and cover an area of about 3000km^2 and has control of over 60,000 km^2 [1]. While fairly little of it is shielded from rough seas and shallow (which would make it ideal for floating PV farms) enough area exists in reasonably shallow water for PV farms of a scale impossible on land (Figure 1).

Offshore PV technology will face some of the same challenges as other offshore technologies such as offshore wind and wave energy. These include the added costs due to performing an installation at sea, dealing with the sea depth, the durability and survivability of the materials used and potential environmental and aesthetic concerns.

Figure 1: The Maltese Islands – each yellow square represents the approximate area needed for a 100MWp PV farm. (Image from Google Earth)

2 OFFSHORE INSTALLATIONS

The first three concerns mentioned above tend to make offshore installations more expensive in particular in the case of wind energy where large foundations are needed and the installation is much more complex offshore, requiring dedicated equipment and ships (Figure 2).

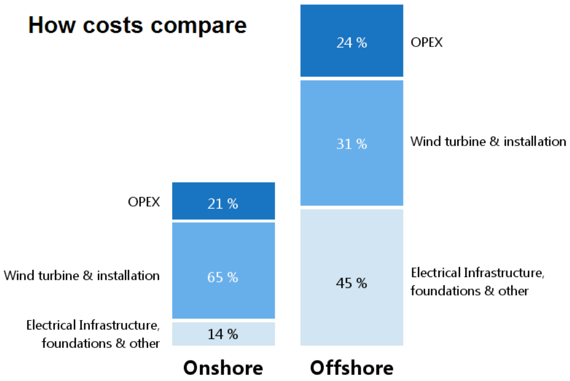

Figure 2: Cost comparisons for offshore and onshore wind installations (from http://www.windpowerengineering.com/design/mechanical/understanding-costs-for-large-wind-turbine-drivetrains/)

However in many ways an offshore PV installation is simpler than a wave or wind power installation:

a. Unlike wave or wind generators there will be no moving parts (added risk of corrosion at joints and risk of sea pollution by lubricants)
b. Anchoring would be similar, though simpler, than wave energy converters as the system can be allowed to move with the waves (as opposed to wave energy converters where swaying with the waves would result in a loss of energy)
c. No massive underwater structures are needed.
d. A sea based PV system could be installed closer to shore than either wind or wave systems since for the former there could be greater aesthetical concerns and for both the installation is dictated by where the most favourable wave or wind conditions exist. A sea based PV system will present limited aesthetic concerns due to the low profile of the structures and can be installed anywhere (in fact a partially shielded area closer to shore would be preferable).
e. A PV system could be modular – and be as large as space permits. The module can be fairly small – not the case with either of the other technologies.
f. The presence of the sea water could actually improve the performance of the panels due to cooling (especially in the hot summer months).
g. While high waves are observed on the Mediterranean Sea in certain regions around Malta (and these locations would typically be the ideal locations for wave or wind generators), such a system would be installed in an area where such waves are unusual and therefore easier to secure. [3]

There are also some disadvantages when compared to wind and wave:

a. Unlike wind, no infrastructure exists for such installations.
b. If conventional panels are laid flat they will produce about 15% less energy relative to panels installed at the more typical 15-30° south facing. However flat installations offer the advantage of not requiring orientation. [2]
c. The panels have to be coated (or specially constructed) to avoid salt-related corrosion over a long period of operation.
d. Salt drying on the panels could reduce the output though this could be eliminated by periodically wetting the panels (offering the added advantage of cooling).

So, while the limitless space makes sea-based installations attractive, cost effective and workable solutions would have to be found to all of the above issues to make a sea-based installation a practical reality.

3. EXISTING INSTALLATIONS

There are currently only a handful of PV systems installed on water. Most are installed on lakes, reservoirs or ponds where salt-related corrosion and large waves are not an issue. Installation on ponds is typically done to make use of otherwise unusable area. The surface structures also reduce the surface area of exposed water, thus reducing evaporation and may reduce algal growth due to reduction in sunlight penetrating the water. If the panels are in direct contact with the water the cooling effect of the water would also improve yield in hot climates. Moreover on ponds and calm lakes one is at liberty to anchor the system with panels oriented south at the right angle for the location's latitude without having to worry too much about drift. In sufficiently calm water one could even envision rotating the system east to west during the day to track the sun's path.

This is the solution adopted by one group in Suvereto (Livorno, Italy) and Pisa (Italy) [4]. The developers of this system on a small lake tried both a system whereby the panels are placed at the optimal inclination for their latitude (40 deg) with a reflector in front of them (Figure 3) and later a system whereby the panels where placed horizontally and reflectors where placed on either side of the panels (Figure 4).

Figure 3: Setup in the Suvereto installation where the panels are installed at the optimal inclination with reflectors in front of them. The whole platform rotates to track the sun's position [4].

This latter configuration offers the added advantage of having the panels in close proximity to the water and thus provides cooling. It also solved some initial problems the authors encountered with the first setup whereby they were getting non-uniform illumination of the panels.

Other studies have not reported this problem, which was probably due in the Suvereto case to the overly specular reflectors whereas other studies used reflectors which were less specular [5]. However they also reported much better generation results with the second setup, so this was naturally preferred.

Figure 4: Setup adopted at the Pisa installation with low level concentration. The plant rotates to track the sun's motion [4].

Others have simply opted for a "standard" installation of inclined panels facing south. This was the case for example at Far Niente Winery installation (Napa Valley, California, USA, Figure 5) where the operators also reported a 1% increase in production (due to the cooling effect of the water), a 70% reduction in water evaporation from the pond and a reduction in algal growth [6].

Figure 5: The Far Niente, California, system.

The approach adopted in Aichi, Japan was to lay the panels flat, maximizing energy density per square meter and facilitating panel cooling. Two systems were installed on a lake. One system was water cooled and one was not. The cooled system performance exceeded the other system's performance by as much as 10% in summer and 3% in winter (Figure 6) [7].

Figure 6: System in Aichi, Japan. 2x 10KWp, one water cooled. [7]

This approach was also adopted in Solarolo, Italy. This system was again installed on pontoons in a lake with air-cooling ducts below the flat panels. (Figure 7). This 20kWp project was dubbed "The Lotus Project" and the motivations for its installation was similar to the other project – not utilising arable land, reduction of water evaporation from the water reservoir and reduction of algal growth. These reasons were recurrent themes in all the existing systems together with the ability to cool the PVs.

The challenge of installing a system at sea will offer some of the same advantages (no utilisation of land, cooling) but not others (algal growth). It also will offer additional challenges such as environmental concerns and dealing with waves and the corrosive marine environment.

Figure 7: System at Solaralo, Italy. (From: http://www.luceonline.it/web/en/ricerca/costruzione-del-primo-impianto-fotovoltaico-galleggiante-in-puglia/)

Other floating systems include a 30kWp tilted panels on pontoon system in Sonoma and a system in Petaluma, both in California, USA. The company installing these systems claims a 70% reduction in water evaporation from the ponds as an added benefit. They are also testing a low level concentrator system.

A small system on a reservoir has also been built in Singapore with plans to build a 2MWp system. And a 135kWp system in New Jersey also had to deal with the added challenge of freezing of the water reservoir on which it was mounted in winter [8].

Figure 8: A 477kWp mixed ground-mounted, water mounted system in Napa County, California. (from:http://www.waterworld.com/articles/2011/09/floating-solar-systems-provide-power-environmental-benefits.html)

Others are considering concentrator systems floating on water. In addition to the systems already mentioned above [4], systems have been installed in Korea and San Diego. These systems rely on the water to cool the cell in the concentrator system. Both these systems claim that they can bring systems to market at a lower cost than conventional systems. Similar projects relying on concentration were also installed in India, Australia, Israel and France. The full tracking system in India is being designed specifically to maximize the energy generation on hydro-electric plants and uses a full-tracking lens with a cell in contact with the reservoir water [8].

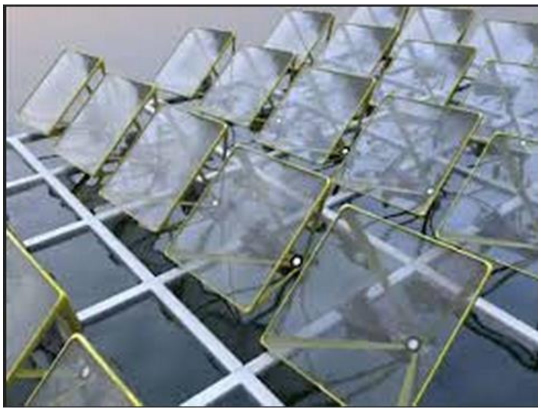

Figure 9: The system being tested in India (from: http://inhabitat.com/sunengy-develops-new-floating-liquid-solar-arrays-to-maximize-energy-output-of-hydro-plants/)

Various other projects and experiments are in the works. These include our own "SolAqua - Innovative Photovoltaics on Water" project funded by MCST (Malta Council for Science and Technology) R&I 2012-041 where we will be launching our first prototype in Maltese waters this spring. Two more prototypes will be launched in the following two years and each one will be monitored in open sea for at least 1 year. Another project with Maltese links is a project in Canada where the proposal is to have flexible PVs floating directly on the sea [9].

There are also many visionary projects – most of which are still just concepts on paper. Some combine several technologies such as Floating Wind and Wave energy generators in addition to solar energy and some propose massive scales – which presumably would make them economically viable and solve the survivability at sea issues. Others focus on the gains obtained by having the system semi-submerged (and therefore cooled, Fig. 10) or focus on a modular low cost way of floating the panels [10, 11].

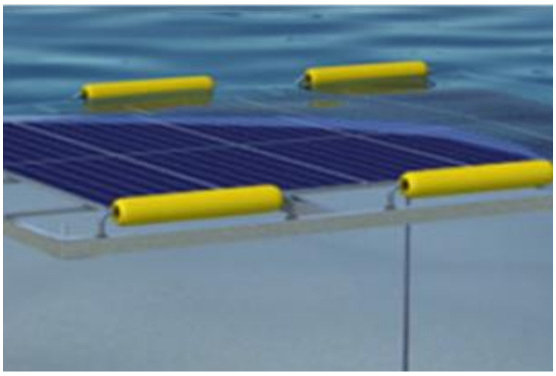

Figure 10: SP2 – Submerged Photovoltaic panels [11].

Fully submerged solar panels are also the subject of some studies [12]. However, due to the shifting of the radiation towards the green and blue side of the spectrum underwater, silicon cells become much less efficient once they are more than a few centimetres below water. Other semiconductors (GaInP) have been shown to have better performance than silicon under water. These of course cost a lot more expensive and this limit their use to speciality applications [13].

4. COST OF PV SYSTEMS

The ultimate metric by which any commercial system will be judged is cost. Looking at traditional systems, photovoltaic (PV) installations have increased exponentially over the last few years fuelled primarily by the dramatic drop in prices for PV panels in the last few years [14]. This price drop has recently levelled off as all the gains were exhausted (Figure 11) [15, 16]. The expectations now are that current system costs will continue declining albeit at a slower rate as further costs are squeezed out of the manufacturing of panels, inverters and other components [17, 18].

Figure 11: Small scale PV system costs [15].

Until a new technology resulting in a step function drop in prices comes by we should expect prices to stay stationary or continue dropping gradually until they reach some eventual plateau.

The price of a PV system is composed of many components and as the price of panels has decreased, the balance of system costs has increased as a proportion of the total cost of a system. The mounting structure for a ground mounted system of a large installation can now represent as much as 12-15% of the total cost of a system (Figure 12) [18].

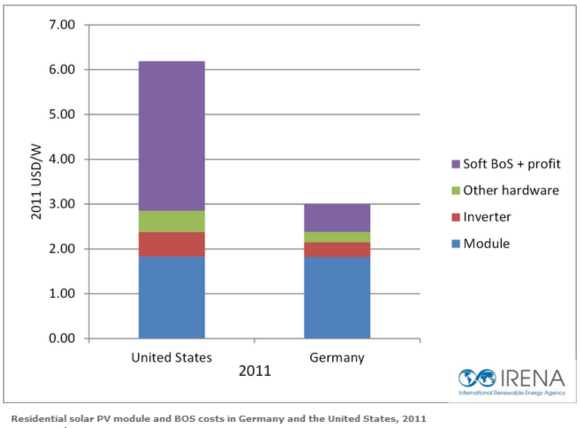

Figure 12: Residential PV modules and Balance of System cost for a residential system in the US and Germany.
(source: http://costing.irena.org/charts/solar-photovoltaic.aspx)

5. OFSHORE SYSTEM COST

If we now consider a traditional PV system on water, the main difference in the overall structure is some floating mechanism (e.g. Pontoons) which could replace a mounting system on the ground. In addition a floating PV system, will require complete waterproofing of all components and anchoring. To give it cost parity with a ground mounted system, these components have to cost 10-15% of the total cost of the system since they would essentially be replacing the rigid mounting system on land. While this is a challenge it is probably possible, especially for large systems.

In a lake or pond setting, as the ones displayed above it is possible to have the panels at the correct angle for the location's latitude to maximize output, since the pontoons could be held rigidly year round. The 10-15% loss in output due to the fact that the panels would most likely be close to flat in an offshore setting could be made up due to the cooling effect of the water which increases the panels output by a comparable amount [2, 4, 7]. If on the other hand the panels are tilted, the structure costs would be similar to those on land but gains could be obtained by cooling the panels.

The cost of land is also significant, especially in a place like Malta where plots suitable for PV Farms can cost as much as EUR 30 per square meter. [19] Leasing such a plot of land can therefore add 15-30% to the cost of a land based PV system over the lifetime of a project – costs which could presumably in large part be avoided if the system is based at sea.

Taking all these factors into account it is not unreasonable to assume, that if the technological issues are overcome, an offshore system could prove to be cost-effective. One could reduce cost further by designing panels specifically for sea use – i.e. making them buoyant and using materials specific for sea use – and eliminate materials unnecessary in this scenario (such as a heavy aluminium frame). If the panels are submerged one might even be able to use cheaper materials for the panel (instead of the tempered glass) since hail damage becomes a lesser issue.

6. TECHNOLOGICAL ISSUES OF SEA BASED SYSTEMS

Salt corrosion, loss of output due to drying salt or glass fogging and biological fouling are all issues that have to be catered for when dealing with a marine environment. Additionally any system at sea has to be able to withstand storms and high winds.

There are various ways for dealing with the loss of output issues – first by having the right materials/coatings that withstand a saline environment and secondly either by having the panels semi submerged or running water over them periodically. It is not entirely clear how much the salt drying will adversely affect the performance of the panels since little or no data exists in the literature. This salt related degradation is currently being studied as part of the SolAqua project. Biological fouling is a problem that will have to be dealt with in a similar way to that adopted by boats or other marine based objects.

There are various ways to deal with the survivability aspect. One may opt to create a structure that is large enough to withstand any weather. [7, 8] Alternatively one may opt for small, modular units. Clearly here size and shape can have an impact on how the object interacts with the waves, and this design aspect will be another focus of our SolAqua project. Finally some have proposed having the panels flex with the waves – which presumably would lessen the stress on the mooring but other issues (such as material fatigue in the panels over time) have to be overcome [9].

7. CONCLUSIONS

Photovoltaic panels have been installed in every conceivable location on land, in space and in the air. So it was natural that floating systems would eventually be considered. The first systems have been installed on ponds, small lakes or open reservoirs – dead space and often close to where the power is consumed.

The next logical jump is to look at offshore installations. Small islands and dense coastal cities have limited space on land close to where the bulk of the consumption is happening. Malta is one such case where it land usable for PV farms is extremely scarce and expensive, and more than enough area is available at sea.

To make it viable any offshore system will have to be able to produce power at a similar cost to land based systems. The pluses and minuses in the balance of system probably make this a possibility even with a system using conventional panels floated on pontoons and anchored to the bottom in reasonably shallow waters. However what would make offshore systems more attractive would be if a solution custom designed for this use was developed. Technological challenges such as long term survivability and performance and biological fouling while challenging do not seem insurmountable.

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