Potential regions in the GCC to deploy Off-Shore Floating Photovoltaic system – A better solution

Abstract:

Generating energy needs by means of renewable sources is a vital strategy for all the GCC countries. Photovoltaic systems in the GCC have been a primary choice of renewable sources due to regional weather and high levels of irradiance. However, the unfavorable environmental factors such as high temperatures, soiling, and dust have been a concern in PV performance. Offshore photovoltaic systems can provide a solution to mitigate these issues and improve system performance. So far, the Floating PV systems have remained unexplored in the GCC region. This paper identifies and presents the six potential regions in the GCC to deploy the Floating PV system based on three environmental factors.

Keywords: Floating photovoltaics (FPV); Gulf Cooperation Council (GCC); PV maximum output Power (P_{max}); Practical Salinity Unit (PSu); Sea Surface Temperature (SST).

1. Introduction:

The rise in temperatures (climate change) that is being witnessed globally, has led to the concerns and initiatives to reduce or perhaps eliminate the use of resources (fossil fuels, carbon emissions, etc.) which are contributing to the global warming (Umar, 2019). Many countries are revising their energy generation methods by integrating the renewables energy into the main grid. The possibility of generating all energy needs by renewables means is seen to be gaining the momentum. It is estimated that most of the countries by 2050, can generate their energy needs by 100% renewable sources (Honnurvali, 2019). The visions of the GCC (Gulf Cooperation Council) member states highlights the importance of diversifying the economy in contrast to their huge dependence on oil & gas sectors for the wealth generation (Umar, 2016), (Saima Munawwar, 2014). One of such visions is to adopt the renewable energy sources (especially solar and wind) to meet the energy demands and to combat the climate changes and carbon emissions (Umar, 2018), (Umar, 2017) has emphasized the adoption of renewable energy sources into the energy mix is not only to take preventive measures for climate change and reduce carbon emissions but also a move towards sustainability. After the renewables readiness assessment studies conducted (Alam Mondal, 2012) by various private and public authorities in the GCC, the installation capacity of solar energy has seen a significant boost (since 2014) with the current installation capacity reaching to 7GW (N.W. Alnaser, 2019). However, the GCC state countries are well known for their hot temperatures, sand storms, and humid climate (Umar, 2018). On the other hand, the performance of the photovoltaic modules is profoundly affected by these environmental factors.

Despite of the availability of high levels of irradiance (2000-2500 kWh/m^2/yr.) and clear skies (average annual sunshine of about 10h/day) during most of the year, the dusty (windblown-sand particles, emission from the vehicles and industry chimneys) and hot temperatures in the GCC member states have been a primary concern for the local stakeholders in estimating the return of investments. (Kazem, 2016) has reported an energy loss of 35-40% of the PV productivity if not cleaned within three months. (Shaik, 2018) has reported that the PV panels installed in hot climatic zones have observed with higher degradation rates of the maximum output power (P_{max}). The effective energy yield of the PV system in the GCC member states require a regular cleaning process and inspection, thereby contributing additional expenses to the stakeholders. Although the concerns discussed above are alarming, but they are not a discouraging factor for further deployment and investment.

Offshore Floating Photovoltaic systems can be an effective solution to address the heat and dust issues in the GCC member countries. All the member countries are surrounded by sea (Arabian Gulf and Gulf of Oman) whose surface water temperatures range from 16^0C to 34^0C in contrast to the land temperatures which can raise from 50^0C to 55^0C during summer. Operation and performance of the PV cells are highly influenced by the operating temperature, Generally, increase in operating temperature will decrease power generation performance of the PV panel (Swapnil Dubey, 2013) and resulting in higher solar energy generation costs. The evaporation process in the sea is likely to reduce the dust formation on the PV panels.

2. Current progress and challenges of solar energy in the GCC

2.1 Current Progress:

Solar energy installations have seen rapid growth since the past two years in GCC countries. Figure 1. shows the current and future planned solar projects in the pipeline to be deployed in the GCC countries (N.W. Alnaser, 2019). In Oman, the current PV solar installation capacity has reached to 1.4MW and with future planned capacity of 100MW (News, 2018). UAE has stood in forefront with highest installations capacity (114MW) among the GCC countries. The near completion of 1.2GW (Noor Abu Dhabi) single solar site project and recent tender release of further 2GW project show the commitment towards sustainable energy (parnell, 2019). It is believed that this could be largest solar project to be built in the GCC member countries. However, Saudi Arabia has recently signed a memorandum of understanding (MoU) to construct 2.6GW solar project at the mecca region (Martin, 2019). Although the solar industry has seen a rising trend in some GCC countries, similar pace seems to be absent in Bahrain and Oman as discussed in the challenges section below.

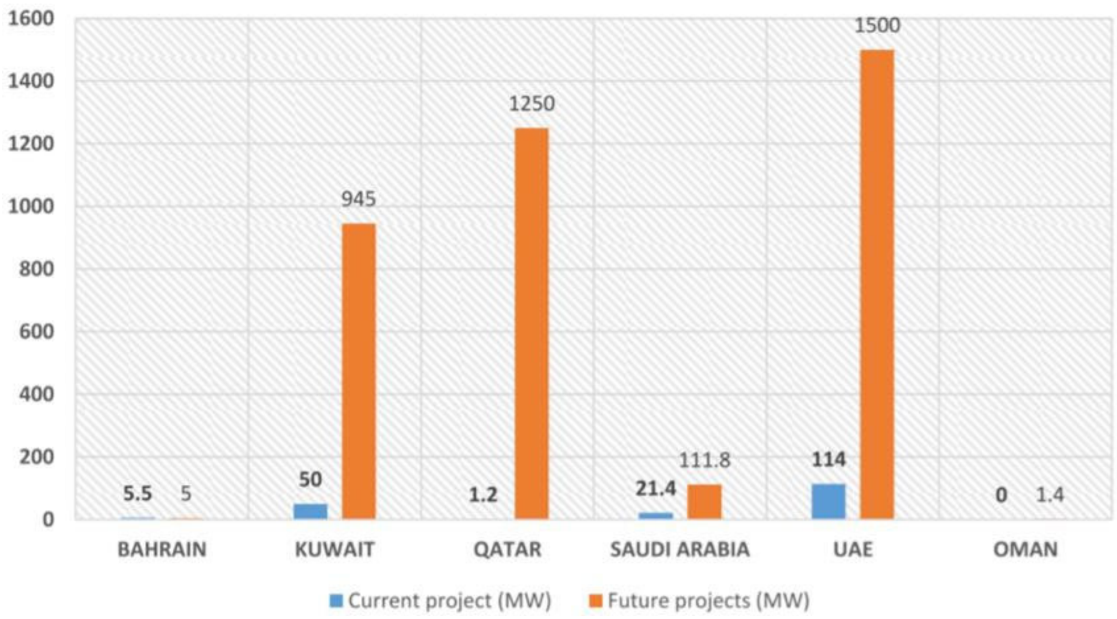

Figure 1. Current and Future solar projects in the GCC countries [(*(N.W. Alnaser, 2019)*].

2.2 Challenges faced by the solar industry in GCC countries:

2.2.1 Soiling and dust:
The land area in the GCC countries is mostly covered by finite granule desert sand or dry land with minimal vegetation activities. (Salem, 2018) has reported that the central gulf region experiences high-speed winds in the range of 8-9 m/s (30 m elevation). If the wind speed grows more than 3 m/s, it can cause the sand to rise into the air thus forming dust leading to soiling phenomenon on the PV panels. The other forms of the dust that are likely effecting the PV systems in this region are the emission from the nearby industries and pollutants. An experimental based study in Qatar region by (N.W. Alnaser, 2015) has noted that deposition of about 5-12mg/m^2 dust can reduce the PV power drop by up to 40% of the maximum value. The PV output power drops as a function of dust accumulation is given by equation (1).

$$PVD\ (in\ \%) = \left(\frac{PV^d}{PV_{nd}}\right)_{drop} = 100 - 99.66 \times e^{-0.035 d_s} \quad (1)$$

Where PV_d is the output power from a dusty panel, PV_{nd} is the output power from the cleaned panel and d_s is the mass per unit area. A recent study *(Hussein A.Kazem, 2019)* conducted in six cities of Oman has noted the PV output power drop is around 60% if not cleaned for a month. Figure 2 shows the reduction in output power in the six cities.

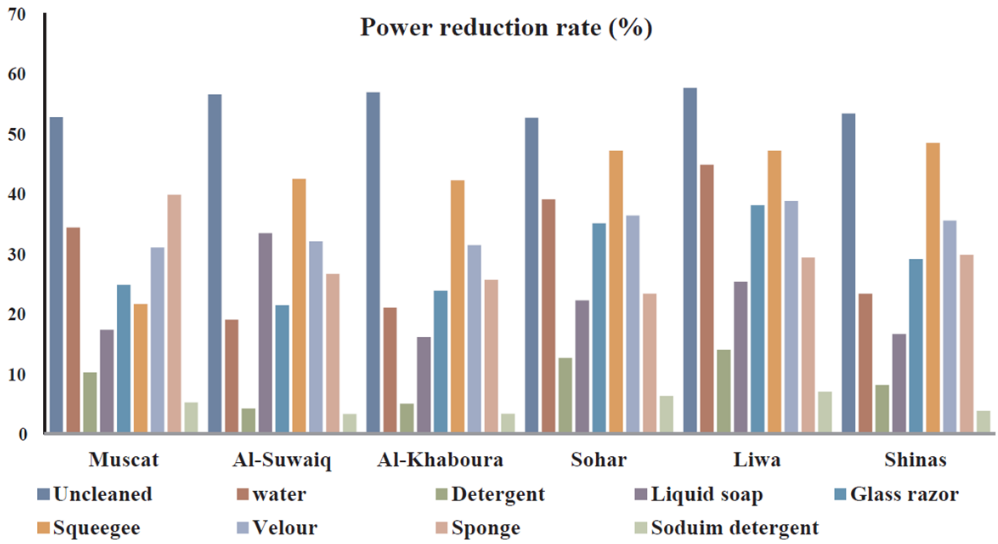

Figure 2. The impact of cleaning tools and chemicals on the PV power reduction rate [*(Hussein A.Kazem, 2019)*].

The cleaning of PV panels using sodium detergent has shown better results in all the six cities. However, usage of such special detergents causes addition of cleaning costs which again reflects in costs of solar energy generation per kWh and can be more expensive than the conventional grid electricity.

2.2.2 High temperature and its effect in PV output power:

One of the key factors that have a critical impact on the Solar PV power generation is the temperature. Increase in temperature causes the decrease in PV cell performance due to increase in internal carrier recombination rates (A. A. El Amin, 2017). Hence, temperature has negative linear relation with respect to the PV cell efficiency (i.e. increase in temperature causes decrease in cell efficiency). (Dubey, 2017) has noted that the modules installed in hot climatic conditions have shown higher maximum output power PV degradation rates than the other climatic zones. (Shaik, 2018) has also reported that based on the type of PV technology, silicon-based PV panels have shown higher degradation comparatively with the thin-film technologies. However, silicon-based PV modules have higher efficiency and costs than thin-film technologies. Further research studies are required to reach an appropriate conclusion that which PV technology type would be better performing and suitable in hot climatic regions. On the other hand, the PV cell temperature can be reduced by adopting appropriate cooling methods. (Hasanuzzamana, 2016) has noted that passive liquid cooling system can reduce the PV cell temperatures in the range of 6^0C to 20^0C thereby increasing the efficiency up to 15.5% maximum. Similarly, active cooling systems (liquid and air) can further decrease the cell temperature by 30^0C with an improvement in efficiency up to 22%. However, adoption of cooling techniques increases the cost of electricity generation.

3. Potential areas for Off-Shore floating PV systems in the GCC

The growth of floating PV systems is not having the same increasing trend as the standard land-based or rooftop PV systems. However, it has attracted enough attention due to its flexibility and performance advantages (recgroup, 2018) and seems to be a promising technology in the future. The unfavorable environmental factors (hot temperatures and soiling, dust) have been a concern in the GCC countries to maintain the high performance of the PV modules. Floating PV systems perhaps could be an appropriate solution to address these issues and also be a better option for land-scarce countries like UAE and Bahrain.

Earlier the floating PV systems installations were limited to inland freshwater bodies. However, this limitation has been overcome due to some recent advancements in technology (Umar, 2017). The shallow water regions of the Arabian Gulf and the Gulf of Oman are shared by all the GCC countries and can be an excellent source in deployment of floating PV systems. This study has showcased the potential sea areas in the Arabian Gulf that can be used in installing floating PV systems. The criteria for choosing these regions are summarized into three main factors.

3.1 Depth of the Arabian Gulf and the Gulf of Oman:

The optimum depth level for the smooth installation and operation of offshore PV systems is five meters (Kim, et al., 2019). General Bathymetric Chart of the Oceans (GEBCO) is the leading organization in the world that maps the world's oceans data sources such as depth, sea surface water temperature (SST), etc. The average depth of the six proposed regions in the GCC is obtained from the interactive maps (noaa.gov, 2019) per $10m^2$ area. Table 1. displays the average depth (in meters) estimated in the six regions of the GCC. Installation of FPV system lower than five meters may likely raise security concerns due to seasonal high tidal waves and surface water level fluctuations. Generally, the average tidal wave height depends on the season and period of the day/night (i.e. full moon nights are likely seen with high-level tidal waves than the regular times). Although, Installation of FPV systems closer to border area (i.e. at lower depth level) may reduce the cabling costs, However, there can be significant challenges in terms of security due to high and forcible tidal waves which may cause serious damage to the entire system. Similarly, the surface water level also experiences fluctuations due to annual warming/cooling cycle process of the sea. Almost from six to eight months in a year, the GCC countries experience hot climatic conditions during which the seawater warms and expands causing increase in surface water level. On the other hand, during winter, the water cools and contracts to cause to decrease in surface water level. Therefore, installation of FPV systems closer to coastal area with lower water level depth (less than 5m) is not recommended. Another prime advantage of the proposed potential six offshore FPV regions in the GCC is that they are nearer (within15 to 20 Km reach) to already established oil and gas power stations where integration of the generated power tends to become easier. Installation of offshore FPV systems at the water depth level greater than 10m is not economically practical as this can increase the mooring system costs. A further research study is required to understand the best economically feasible mooring system technology that can be applied in GCC Arabian gulf sea waters.

Regions	Askar (Bahrain)	Kuwait bay (Kuwait)	mina al fahal (Oman)	Jumeriah (UAE)	Al-kohr (Qatar)	jubail (Saudi arabia)
Average depth in meters	6	6.5	7	10	5.5	8

Table 1. Average depth in the six potential regions of GCC countries.

3.2 Salinity levels of the Arabian Gulf and the Gulf of Oman:

Arabian Gulf and the Gulf of Oman are the semi-enclosed sea parts of the Arabian sea surrounding the GCC countries on the west side and Iran on the northern and eastern side. Due to rapid industrialization and population growth in the GCC countries the demand for freshwater usage has seen a tremendous increase. Due to lack of natural freshwater resources, desalination of seawater has been a primary choice in the GCC countries to meet the needs of freshwater. It is estimated that by 2020 (Asaba, 2018) there could be a need of around 5500 million imperial gallons a day (MIGD). To meet the freshwater demands several desalination plants have already been deployed across the coastal length of GCC countries. The salinity levels of the Arabian Gulf and the Gulf of Oman are considered to be hypersaline in nature compared to other offshore regions of the world. This is due to the hot, arid climate of the bordering lands which have higher evaporation rates leading to hypersaline conditions. Secondly, the waste remnants salts from the desalination plants called brine (2.5 times the seawater salinity) are released into the existing seawater. The orange curve in the (Figure 4) displays the salinity levels of the proposed six offshore regions in the GCC countries. The secondary axis shows the salt PSu units, one can notice that the Kuwait region has fewer salinity levels due to freshwater inflows from Tigris, Euphrates and Karun rivers; and higher salinity levels in the regions of UAE and Qatar sea waters. However, the salinity levels (PSu units) of the surrounding sea areas of the proposed six potential offshore regions are higher than the proposed offshore regions. Higher salinity levels of the sea can cause corrosion of the PV panels and the high salt concentrations in the air also reduces the efficiency of the solar panels. Therefore, PV panels manufactured with anodized aluminum frames are highly recommended in this region. Further, the PV panels must have passed the IEC 61701 salt mist corrosion test to be able to withstand these harsh environmental conditions. On the other hand, (Gretkowska, 2018) study has noted that an increase in elevation of PV panel above the sea surface can reduce the effect of salt formations on the PV glass.

3.3 Sea Surface Temperature (SST) Effects:

The sea surface temperatures of the proposed six offshore regions are displayed in Figure 4. The primary axis shows the temperature in ^{0}C and the blue bars shows the respective temperatures for each region. The source for acquiring this data is from National Oceanic and Atmospheric Administration of the United States (noaa.gov, 2019). The SST of the potential regions is lower by at least 10^{0}C to 15^{0}C comparatively with the land temperatures. The lower sea surface temperatures help the PV panel to maintain the reduced operating temperatures, thus increasing the efficiency. The report (Bhattacharjee, 2018) claims that the plants operating in floating form have higher efficiencies in the range of 5-16% compared to land-based PV plants The evaporation mechanism helps in decreasing soiling and dust formation. Figure 3 shows the potential regions in the GCC to deploy the floating PV systems. The study and analysis of potential electricity generation in these areas will be presented in a full research paper.

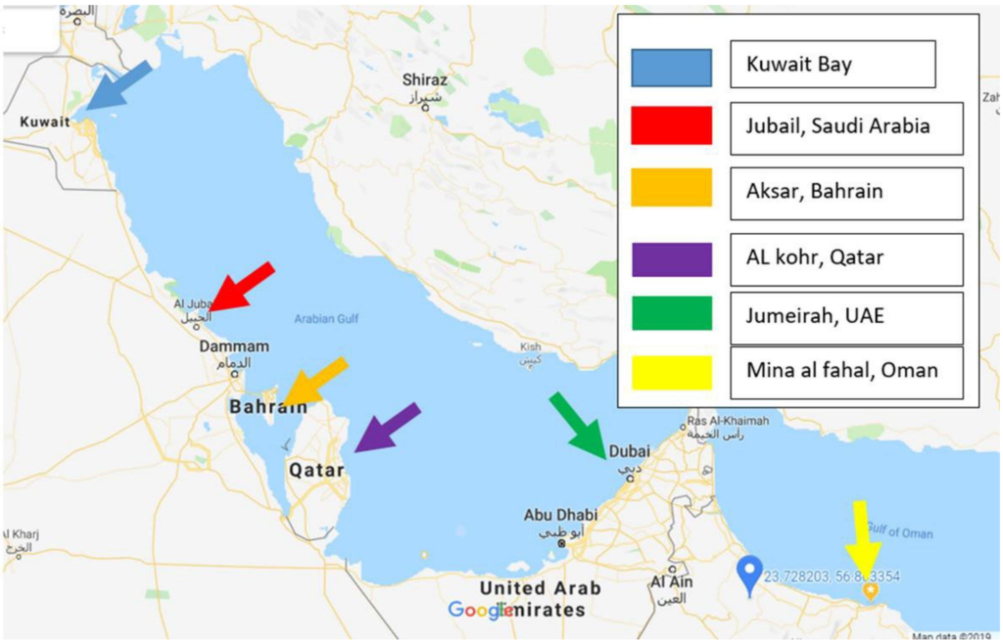

Figure 3. The potential sea regions in the Arabian gulf for deploying Floating PV systems.

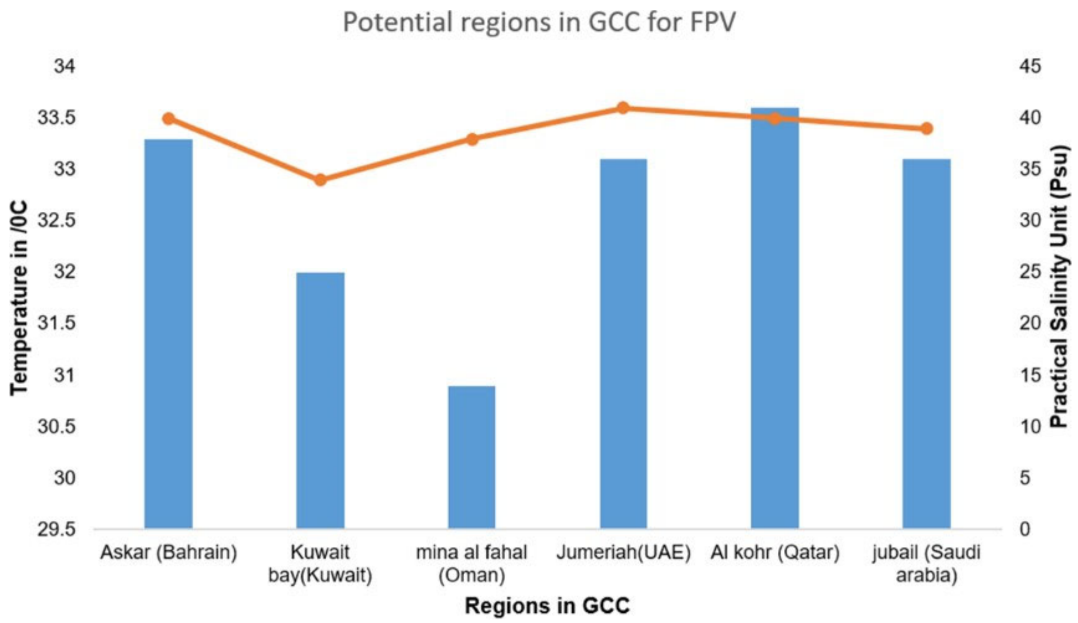

Figure 4. Average Sea surface temperature and salinity in the potential GCC regions for FPV.

4. Conclusion

The hot and dusty climatic conditions in the GCC countries have been unfavorable to achieve the high performance of the PV modules. However, the offshore Floating PV system has a great opportunity and scope to address these issues. The lower seawater surface temperatures and evaporation mechanism help the PV panel to perform effectively than standard land-based installations. Potential areas in the GCC region have been identified to deploy the offshore floating PV systems. A comparison study in potential electricity generation and cost analysis between a standard PV system and FPV system in the GCC regions, are the research areas which need to be addressed further.

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