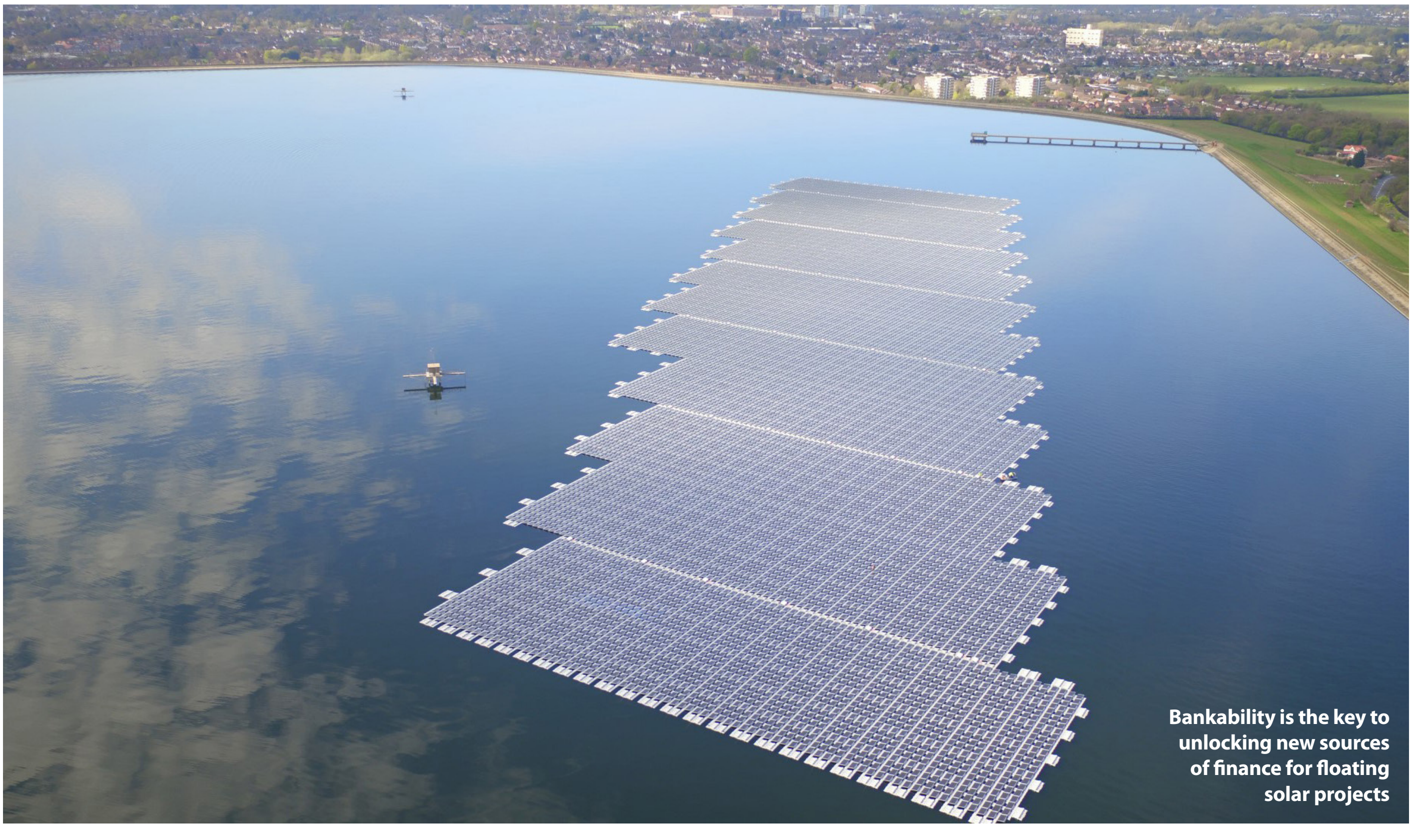
Technical considerations to ensuring bankable floating PV projects

Design | As larger floating solar projects become a more common sight around the world, bankability is increasingly coming to the fore to satisfy the demands of financiers. Jeremy Ong, Ken Tay and Harald Hammer look at some of the areas where careful due diligence is vital to managing and mitigating technical risks for lenders



Bankability is the key to unlocking new sources of finance for floating solar projects

Credit: Lightsource

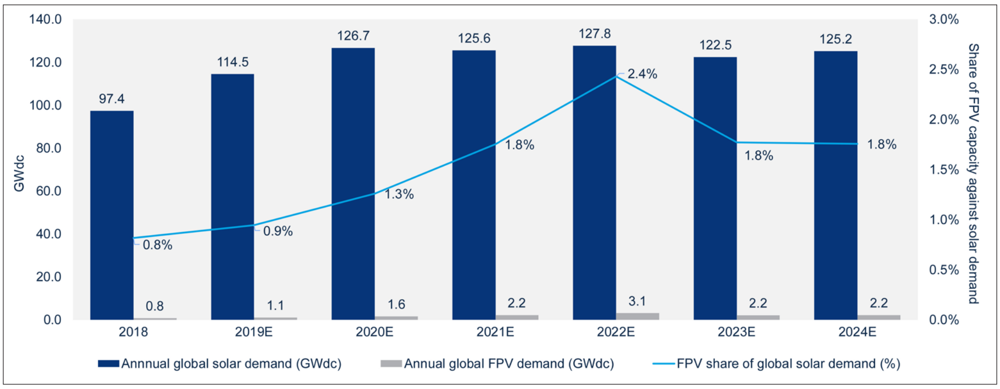
The growth of floating PV gloablly and the increase in project sizes has led to the need for lenders to provide financing to support these projects. In such instances, experienced advisors are requested to provide due diligence and to ensure technical risks for the project are highlighted and can be mitigated.

FPV market evolution

Floating PV as a nascent segment in solar has been gaining momentum globally in the last few years, particulalry in the APAC markets since 2014, and will satisfy just under 1% of annual global solar demand by the end of 2019, and 2% of global solar demand by 2022 [1].

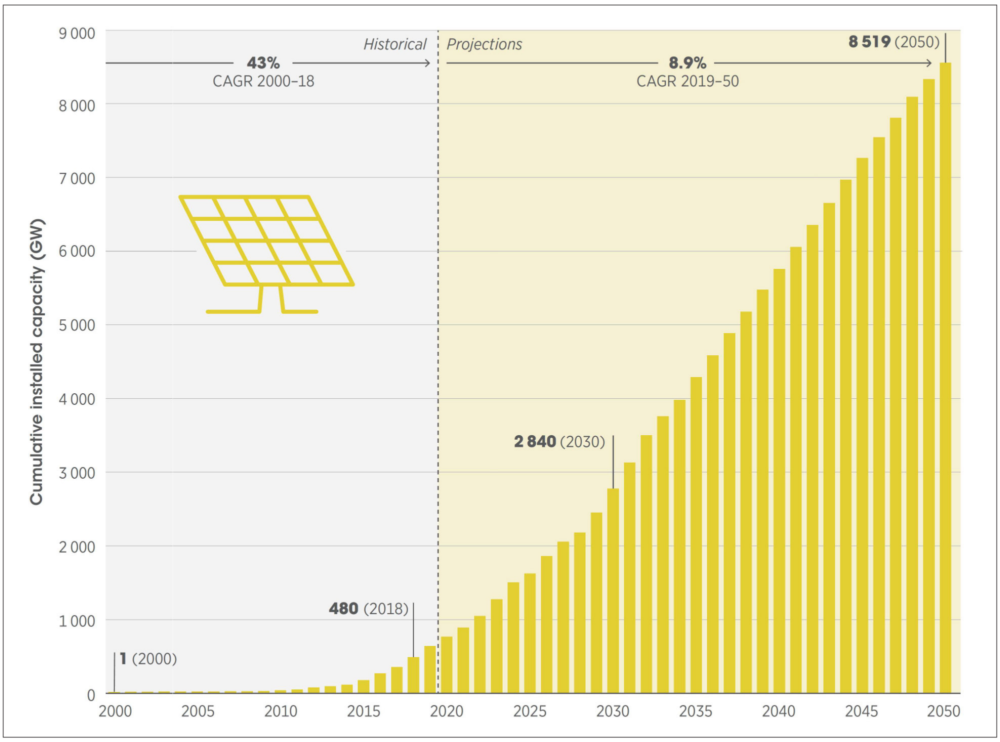
This follows the huge growth in the overall global solar PV market, which grew at a compound annual growth rate (CAGR) or 43% from 2000 to 2018 and will continue to increase at 8.9% CAGR to 2050 [2].

The world's first floating PV project was a 20kWp system started in Achi, Japan in 2007. From there most FPV projects were small test prototypes of less than 100kWp until mid 2014. The Fukushima Tsunami disaster in 2011 resulted in the Japanese governement shutting down the country's nuclear plants and creating a new policy and generous feed-in tariff of JPY42 for PV systems [3], and also stimulated the growth of floating PV in Japan [4]. The majority of these projects were smaller in scale at less than 2MWp, enabling



Credit: Wood Mackenzie

Figure 1. Annual global solar demand (GWdc), annual floating PV demand (GWdc), and FPV share of global demand %.



Credit: IRENA

Figure 2. Compared to 2018 levels, cumulative solar PV capacity is expected to grow sixfold by 2030, with a CAGR of nearly 9% up to 2050

developers to build them on equity and without requiring non-recourse project financing. Therefore, many of these early floating PV projects built in Japan at that time will not have undergone a very rigorous due diligence. The other large market taking off was China, nearly at the same time in a parallel trajectory. In China, the projects were not small but much larger in size of up to 40MW, and these were developed and built mostly by the local floating system suppliers and then sold to the local utilities after construction and when operating. These projects were also built not with non-recourse project financing but fully on equity.

Interest in floating PV grew because the traditional areas where PV was built on land became more difficult and challenging; increasing land pricing, complexity of multiple land ownership, permitting and regulations on land use changes made floating PV on water bodies a more viable option to consider.

Growing need for project financing

With a growth of larger projects in the APAC region there becomes a need for developers to look at lenders to provide financing; with that, proper technical due diligence also becomes a neccessity from the lenders to help assess the technical risks associated in the technology, design, construction and operational aspects of the floating PV project.

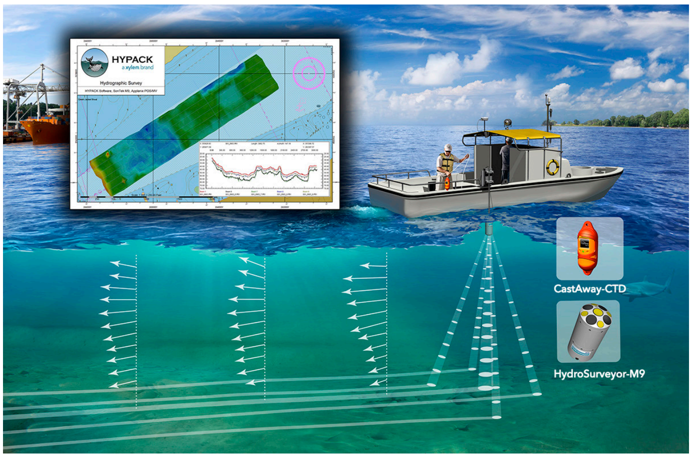
Site assessment

An on-site assessment is critical to gain an appreciation of the actual site conditions. Having such in-situ measurements during the plant design phase will provide a more accurate forecast of the energy resource, good understanding of terrain conditions and identify key potential issues that can be mitigated early on. For a large floating PV project, where the majority of the PV plant will be on the water, one of the main challenges is to identify the conditions below the water surface, which is not possible with just a visual inspection.

Bathymetry and topography surveys

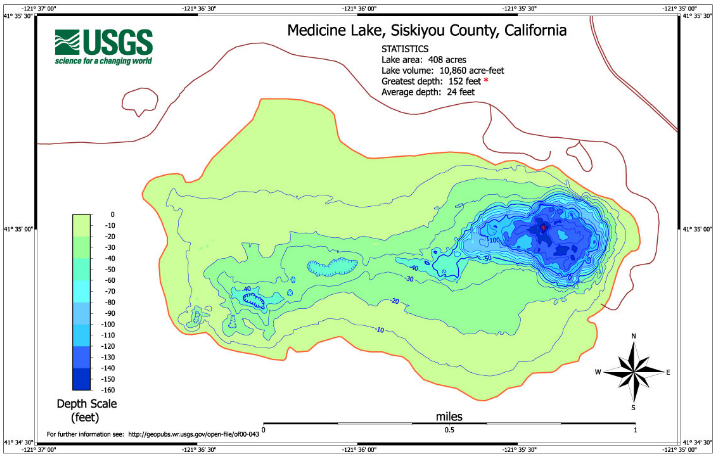
A bathymetry survey is performed to map out water depth variations across a project site and provide a perspective of the underwater terrain of the water bed. For a bathymetry survey at inland water bodies, a portable single beam echo sounder may be mounted over the side of a boat. For large water depths and extensive survey areas or nearshore/offshore, multi-beam echo sounders operated from a dedicated vessel are most suited. The bathymetry survey is complemented by a topography survey of the land area to cover locations for transmission facilities and any anchoring at the banks.

A bathymetry map is a critical input to define usable areas for placing floating PV islands as well as to identify suitable mooring and anchoring solutions. The bathymetry data is also useful to assess whether an anticipated fluctuation of water level due to seasonality may result in some floats resting on the water bed. In addition, any potential clash between the floating PV islands and nearby banks can be prevented with accurate topographical information above and below water.



Credit: SonTek

Figure 3. Bathymetry survey



Credit: USGS

Figure 4. Bathymetric map showing contourlines

Site	A	B	C	D
Water Body	**Reservoir**	**Hydro dam**	**Reservoir**	**Hydro dam**
Area of Water body [Ha]	450	6,200	91,500	32,300
Elevation [AMSL]	0.40	215	1	56
Wind Speed[1]				
Maximum wind speed [m/s]	**40.00**	**22.00**	**57.60**	**20.50**
Maximum average five min [m/s]	5.86	6.00	15.44	5.80
Daily Average [m/s]	1.13	1.60	3.44	2.60
Water Level				
Yearly Average variation [m]	**0.40**	**11.80**	**2.20**	**12.00**
Maximum water level [m]	1.10	220.00	13.50	62.00
Min water level [m]	0.10	207.00	10.60	50.00
Maximum water depth [m]	6.50	94.00	20.10	25.00
Average water depth [m]	2.30	34.90	2.80	4.30

Table 1. Comparisions of four sites a) water body type b) wind conditions and c) water level variation

Geotechnical survey

A geotechnical survey is carried out to identify soil conditions and potential lateral variability of the water bed, particularly at anchoring areas for the floating PV installation. In the survey, information on soil properties at shallow depths, e.g. up to 6m, is obtained from either borehole sampling or continuous probing tests, such as CPT or a combination of both. Shear strength of the sub-bottom soils is used for the anchor sizing for a given design mooring load. The type of suitable anchors is also dependent on the soil condition at the water bed. While concrete blocks are generally applicable for a "hard" bed, other types of anchor, such as pile or plate anchors may be more suitable for relatively soft soils.

For inland water bodies or neashore areas, the survey may be conducted from a floating pontoon or a temporary platform using the conventional soil boring technique. It is important to ensure that the scope of geotechnical survey for floating PV installation is adequate. In order to overcome inherent uncertainties or information gaps in available soil data, field tests on selected anchors may be performed to proof load the design tension force.

Meteorological survey

Design load for a floating PV installation is highly dependent on the anticipated environmental extremes [5] at the site, such as wind speed and any waves and current. For installations at inland water bodies, wind force is typically the predominant loading condition while for nearshore more complex loading conditions induced by wind, wave and current are envisaged.

Design wind speed extremes may be available from a local code but more detailed information including wind directionality may be obtained from a site measurement for at least one-year duration. Extreme value analyses can be performed from the site measurement data and other long-term data from any nearby weather stations to derive extreme wind speeds for various return periods. In the absence of design codes for floating PV, usually a 50-year return period wind speed (3-sec gust at 10m) is recommended for the ultimate limit state design.

Wind-induced waves and surface current may be estimated from established theories. When design optimisation is desired, a detailed measurement of waves and currents together with long-term stillwater level changes at the site can be performed using various remote-sensing techniques such as Acoustic Doppler Current Profilers.

Investment in obtaining accurate site parameters at the early stage of a project should be able not only to optimise the design and its cost but also minimise risks of damage/failure, which might lead to higher costs for remedial measures or even a total loss of the asset. More reliance on updated information should also be emphasised in view of the change in global weather patterns, which show increased frequency of extreme weather events occuring over the last several years.

Site comparisions

Appreciation of a site is important and comparing some aspects of these four sites in Asia shows that they can be very different in each individual aspect, which can affect design requirements in a fairly major way. Table 1 gives a high level overview of the site-specific wind and water level parameters on these four different inland water bodies in Southeast Asia and how they vary. The three parameters to highlight are: a) water level variation on a yearly basis, b) maxmium water depth, c) maximum five-minute wind gust. The maximum wind speed can be seen in Site C at 57.6m/s and it is also has the largest area of water, but the second highest wind speed is Site A with a much smaller water area of 450ha. Site B and D are both hydro dams with relatively simiar yearly water level variation of nearly 12m, but their maximum water depths are very different at 94m at Site B and 25m at Site D; the average water depth is 34.9m at Site B versus only 4.3m at Site D. Also, the daily average windspeed of the four sites vary from 1.13m/s to 3.44m/s, which is three times more than the lowest; this can have a significant effect on the energy yield overall and a significant contribution to long-term future revenues of the project. This highlights how good quality, accurate site and historical data is crucial to both the mechanical design solution, but also to the accuracy in modelling the energy yield of the project (more will be discussed in the section on resource data and energy assessments).

One unique challenge on Site D is that due to changing weather patterns over recent years, in the dry season 30% of the water body will be left dry. This becomes a potential challenge for the type of floating system technology used as currently no float system is designed to ensure safe operation on dry land, as it may be undulating terrain and debris left on the lake bed.

Siting of grid interconnection facilities

In the case of a potential large greenfield floating PV site greater than 50MW, there will potentially be a need to locate and identify a suitable HV substation on land nearby the site to connect and dispatch power. Locating the best technically viable option can be a challenge if the land needs to be converted in line with local land use regulations. Negotiations of leasing or buying of the land may also often become long drawn and complicated, more so with a tight timeline to achieve the commercial operations date (COD). So with this, it is very helpful to have quick assessments on the technical side in calculating the infrastructure cost with an optimal and safe optimised design.

Anchoring and mooring

Actual behaviour of floating solar PV under design environmental conditions is expected to involve interactions of fluid, structure and soil. Although design input parameters for the environmental extremes can be reliably obtained, derivation of the environmental loadings for design purposes is non-trivial in the absence of detailed technical guidelines for the structural aspects of solar PV and floating solar PV in particular.

Several failure cases of floating solar PV plants under typhoon conditions in Japan were reported. Recently a 13.7MWp floating solar PV plant was significantly damaged and caught fire after Typhoon Faxai at Yamakura Dam in Japan (see Figure 8). The storm reportedly came in at an average wind speed of 41m/s, which is apparently higher than the local code required. During the same typhoon, a smaller floating solar PV plant in Ariake Reservoir experienced a different failure mode in which the interior floats were detached from the outer ones and pushed to the shore. Such failures imply that the current engineering practice can be deemed insufficient to safeguard failure of the system or the critical components in the event that design extreme loading occurs within the system's expected lifetime.

Good engineering design takes experience and appreciation of the interactions between the different design desicplines to ensure robust and yet cost-effective design. Solar PV has been a mainly electrically led field and less focused on detailed mechanical, structural and geotechnical aspects of design. With the growing deployments of floating PV at a larger and larger scale, due consideration should be given to the critical elements of floating PV systems, such as float joints as well as the mooring and anchoring system including its connections.

Unlike offshore structures for oil and gas activities, where high redundancies are inherent system requirements to prevent structural failures and loss of lives, mooring systems for floating solar PV pose unique challenges. In view of the typically large quantity of mooring lines and anchors involved in a floating solar array, cost optimisation of the mooring system including the installation and maintenance aspects is of paramount interest. Presently, the number of mooring lines are often determined by a simple distribution of the total design horizontal load according to the strength of the mooring-float interface. No mooring design optimisation has been sought through detailed modelling, such as hydrodynamic simulations, in order to lower the mooring system cost and ease the maintenance without compromising its reliability.

Furthermore, robustness of the current typical mooring system for large floating PV arrays and in more challenging environments such as deep water, highly varying water-bed elevations and coastal area needs to be further investigated. The use of elastic mooring lines or connections has been adopted in several projects to overcome extreme water level fluctuations or anticipated high peak load with the conventional mooring system. Cost-effective key enabling technologies for futureproof large-scale floating PV installations, including at nearshore areas, need to be urgently identified.

Credit: RTS Corporation

Figure 5 Typhoon caused fire on Japan's largest floating PV site on Yamakura Dam in 2019

Technology specification

The appropriate specification of technology for a particular project site needs to look into not just international codes and standards but also consider the local environmental conditions. The emphasis should be on correctly specified PV modules, inverters, combiner boxes and electrical balance of system (BoS) equipment, as well as PV float systems and anchoring and mooring equipment, some of which may not have immediate, but rather mid- to long-term impacts on the performance of the plant.

The majority of all floating PV systems available on the market today are made from HDPE plastic material. It is important for any large bankable project to consider the following tests to show resistance and durability for their design life of 25 years and beyond in their material tensile strength. As there are currently already industry standards for UV testing on extruded and blow-molded plastics to simulate accelerated environmental test conditions under UV light, high temperature and humid conditions, the HDPE samples should undergo UV testing according to ISO 4892-3:2016(E) Method A cycle no.1 for 3,000 hours,

Credit: DNV GL-PVEL

Figure 6. PV module inspection and PV Inverter testing

where these test samples are then tested for tensile strength according to ISO 527-2:2012 plastics determination of tensile properties. The float material should also comply with fire safety requirements and fire hazard tests according to IEC 60692-2 -11 - Glow-wire flammability test method for end-products (GWEPT).

Manufacturing audits and quality inspections

To ensure equipment conforms to the quality stated in the supply contract terms, there should be a manufacturinng audit report by an independent third party, while a manufacturing inspection of the production of the modules and inverters should be a mandatory requirement for developers who are concerned with good quality control for equipment procured for their projects. They should have expereinced and credible independent QAQC inpectors do this on their behalf. This really helps to ensure the manufacturing quality assurance of the products, be they PV modules, floats systems or inverters, is done during the entire process to ensure quality and performance.

Energy production assessment

Weather resource

Compared to a traditional ground-mount PV plant, it is even more critical to accurately assess the on-site wind condition for a floating PV plant for structural loading and foundation design. However, good and long-term on-site measurements of surface winds over water bodies (both inland and offshore) [6] are not always readily available. Due to the localised behaviour of wind patterns, even ground station measurements a few kilometers away from the actual site can be quite different.

An alternative has been to use satellite or reanalysis data sets to assess the on-site wind conditions. These datasets, while useful to provide a general idea of the site conditions, are subjected to higher uncertainty due to inherent modelling assumptions and coarse spatial resolution. Moreover, not all global datasets are created equal. These datasets tend to be validated and tuned using regional ground measurements [7]. The implication being that regions such as Continental United States and Western Europe, with a long tradition of meteorological measurements, are well validated while regions such as the Maritime Continent tend to behave poorly [8].

Site-measured data

For site-measured data it essential to measure the following parameters with sensors of the correct specification: irradiation, wind speed and wind direction, ambient temperature and module temperature, humidity and precipitation. For large utility-scale projects the pyranometers specification should comply to ISO 9060-2018 Class A (secondary standard) and IEC 61724 Class A, with an understanding of the site location requirements on precipitation and temperature range. For the anemometer specification it is important for the sensors to be suitable to meet the historical maximum windspeeds. This is to ensure good accurate site data is collected, not just for the measurement campaign, but also during the operational phase in case of extreme weather events in potential hurricane and typhoon-prone areas. The duration of the measurement campaign should ideally be minimum one year to fully capture the seasonality of the site in a full year cycle, which again will help to reduce the uncertainty of the energy yield estimate. This, in tandem with other long-term historical data, either from other ground measurements or satellite data, helps to provide better correlation and more accurate long term energy forecasts.

As part of the measurement campaign, a soiling station to measure accurate site soiling conditions becomes much more helpful than having guidance estimates, which is good for more mature segements such ground-mounted and commercial and industrial projects.

Loss assumptions for the energy model

An important part of the energy assessment are the loss assumptions being input into the energy model. These losses may seem very small and insignificant at first glance but will all have a compound effect in the long-term energy yield forecast. The emphasis is not on being conservative but rather accuracy with the modelling approach. The following factors are some that are not always included: accurate creation of PV module PAN and PV inverter OND files, thermal loss factors, DC and AC system losses, accurate soiling loss estimates, module specific losses such as temperature coefficients, module qualify factor (MQF), PV module degradation, mismatch losses and light-induced degradation (LID) .

Grid connection review and system studies

There are a few reasons for conducting grid system impact studies for a grid-intergated PV project.

One key point is compliance with the local grid code requirements for licensing, but for the lenders it is to help understand the potential of curtailment and unavailability, and to be able to find mitigation strategies to limit if possible.

The following are system studies that should be done:

Steady-state analysis:

- Power flow analysis (PV generation for peak and light loads).
  - It is important to have load flow results for peak load and light load systems. However, PV loading can be different (20%, 30%, 50%, 60%, 100% etc.).
  - Certain countries require steady-state results for different years as well (e.g. for the next 10 years with five years interval).

Short circuit analysis:

- Power system component loadings to assess the thermal capacity;
- Component rating calculation;
- Operation power factor study;
- A complete contingency study (N-1) for the plant network. (N-1-1 and N-2 might be required);

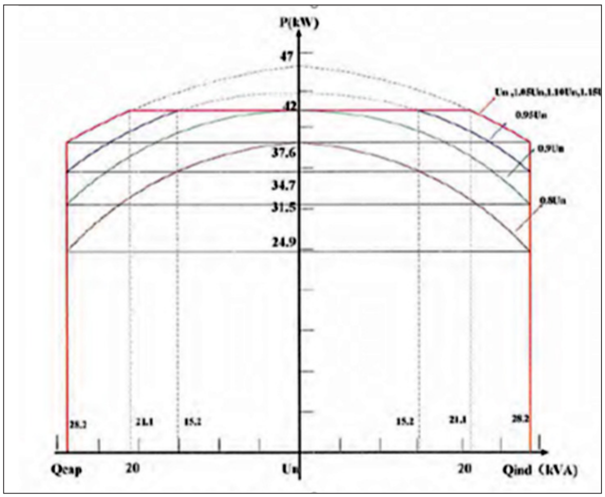


Figure 7. Power quality analysis

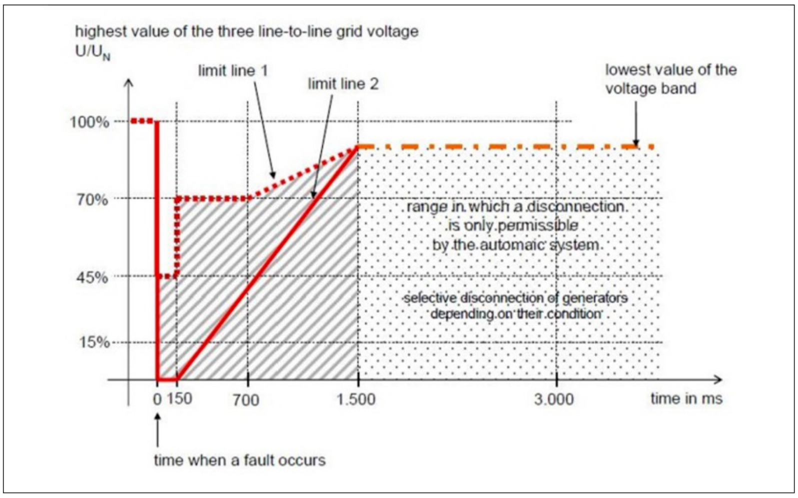


Figure 8. Low voltage ride through

- Reactive power compensation analysis

Power quality analysis (EMT):

- Harmonic study;
- Flicker study.

Dynamic studies (EMT, RMS):

- Transient study;
- Oscillatory stability (eigenvalue) analysis;
- Medium and long-term dynamic studies (30s to 10min);
- Sub-synchronous resonance studies;
- Fault ride through capability study;
- Over frequency analysis study;
- Model validation study (plant modelling methodology).

Grid curtailment

Curtailment risk is a recurring issue that is seen in markets where there is a huge growth in solar being developed in resource-favourable locations and provinces, such as in the early days in China, Japan and more recently in Vietnam. The difficulty is getting good network data and modelling it accurately, something that is not always available. Often in the due diligence process for greenfield projects there is not enough available data to establish the curtailment risks, and there are no easy answers on how this is to be accurately estimated. Every project poses its own challenge so it is ideal to have good local experience and knowledge of the specific grid models where possible.

Conclusion

The emphasis when embarking on a floating solar project is to understand what the major risks are for the particular site, based on a sound knowledge of its specific conditions, and to ensure the energy yield assessments have captured good site-measured inputs to provide accurate long term forecasts. Such analysis will help ensure proper designs that are both electrically and structurally sound and comply not just to local codes but good international best practices. Engaging good and experienced technical advisors with the due diligence process will help reduce and mitigate the major technical risks. ■

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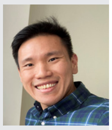

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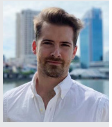

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