Considerations for Developing a Solar Module Spares Plan

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In this updated version of an article published in October 2023, author Daniel Tarico, E3's Director of Renewables, discusses the many factors developers should consider when developing a solar module spare parts plan. Finding the right balance can be difficult, but it will aid in achieving project operational and financial objectives.

INTRODUCTION

Nearly all commercial or utility-scale solar power projects are provisioned with spare solar modules as part of the initial module purchase. Though there is no standard spare quantity required, the industry has generally accepted 1% as a typical number of excess modules to provide an allowance for shipping and installation breakage and maintenance spares sufficient to replace anticipated failed or damaged modules during the first years of operation.

Solar modules continue to develop and change rapidly. It is common for specific modules incorporated into a project to become obsolete and be taken out of production within 24-36 months of being introduced, often before any significant number of module failures occur in operational solar facilities. Modules continue to increase in physical size, efficiency, output voltage, and other performance factors. For operators of facilities, this means that modules requiring replacement due to breakage, electrical failure, or excess degradation must typically be replaced with spares from storage or must be substituted with similar modules if available. Exact replacement modules cannot be expected to be available for purchase as needed after the plant is constructed and operational, particularly beyond 3-4 years after the initial construction of the project. Given this, careful planning is required to ensure that projects have the spare solar modules to continue operations.

Although module manufacturers provide long-term warranties for modules, the warranty support may be formulated as replacement modules with total DC wattage equaling the total of the lost DC wattage or as liquidated damages for lost DC value. Neither form of warranty ensures that the exact original modules will be provided to replace those that have failed. Also, module warranties will not provide replacements for those damaged by extreme weather events, breakage from accidents on site, theft, vandalism, fire, etc. In these instances, the owner must purchase suitable replacements.

> For long-term owners, module failures will be ongoing, will accelerate as the plant ages, and exact replacement modules will become unavailable relatively early in the planned operating life. This scenario requires a strategy for establishing a spares inventory while the modules are still in production.

Operators should regularly monitor the condition and performance of the modules, replace failed modules from spares when it is economically favorable to do so, and plan for future scenarios where suitable replacements may not be available. If system output must be maintained by repowering portions of the plant, operators may need to use newer modules and re-use serviceable modules where they are needed within the facility.

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Though 1% is generally accepted as a sufficient quantity of spare modules for solar projects, the industry recognizes that projects vary considerably in size, location, and type – all factors that will affect the management of spare components and replacements. A project's unique economic features also inform the module spares and maintenance strategy.

For example, if the offtake agreement has a relatively high value for generation or penalties for plant under performance, then the conditions favor greater investment in maintenance and a larger inventory of spares to assure failed modules (and other components) can be rapidly returned to service. In other cases, where projects are subsidized via a capital support structure (e.g., Investment Tax Credits (ITC) and Modified Accelerated Cost Recovery System (MACRS) in the US) it may be more economical to allow steady plant degradation and to reduce operating expenses by minimizing the initial spares inventory and delaying reactive maintenance. In some markets, solar projects are intentionally underbuilt to save on capital expenses. In these cases, the developer or owner accepts the risk that some portion of the plant may suffer large failures due to weather events, but the large initial cost savings offset the risk value of lost plant and production.

The ownership time horizon and intention will also influence spares planning related to long-term maintenance. A developer planning to sell a project at COD or after a short operational period has little incentive to plan or provision for successful long-term maintenance and operation. A long-term owner, by contrast, may have an in-house operations team or retain a specialist organization and develop a complete plan for life cycle maintenance that includes spares requirements, contingencies, late-life maintenance expectations, and decommissioning or repowering and end-of-design life.

PLANNING CONSIDERATIONS

Project-specific module spares strategies should consider several factors that guide the spares purchase quantity and timing. Here are some of the factors that should be taken into consideration.

Project Size: As noted, practitioners in the solar industry have generally accepted 1% initial spares as a rule of thumb. Still, as projects have grown larger, the spares requirement has trended downward in proportion to the total modules on site. Current thinking within the industry is illustrated in the table below for total spares to be included with the original module supply order.

PROJECT SIZE (MW)	SPARE MODULES (%)
50 - 100	>= 1.0
100 - 500	0.9 - 0.5
500 and above	0.4

Module Quality: Module quality (durability/reliability) varies significantly across the industry and even among different module models from the same manufacturer. Reliability depends on many factors beyond manufacturing quality controls, including the type of module, back covering, bill of materials, maturity of technology, handling history, etc. Modules have become more reliable and durable during the past decade. Current module designs are expected to exhibit fewer failures in the field than have been observed in older operating power plants. However, new module technologies are being introduced at a greater pace, and though accelerated testing protocols are sophisticated, operating experience with the new technologies is limited and long-term failure rates are unknown, introducing risk and uncertainty into the long-term operating plan.

Damage and Failure Causes: Even with improved module quality reducing overall failures, physical damage can be expected. Total module orders include allowances for:

Shipping and Handling breakage

- Discovered prior to construction.
- May be re-ordered immediately.

Installation breakage

- Replaced during construction from spares.

Defective/Non-functioning modules

- Discovered during inspections and functional testing.
- Replaced prior to final completion.

Early Lifecycle Failures (1-5 years)

- Failures include cracked glass, junction box failure, hot spots/conductor failures, detected through monitoring systems or periodic inspections.
- Replaced during routine service or sooner if production loss economics justify.
- Modules replaced under warranty with equivalent DC value or manufacturer provides liquidated damages for lost module value.

Middle and Late Lifecycle Failures (6-40 years)

- Detected during routine inspections and maintenance.
- Replaced from inventory if available. Otherwise exchanged for a suitable substitute.
- If inventory or substitute is not available, may require salvaging modules from portions of the plant to maximize overall production.
- It is most likely the OEM will pay liquidated damages rather than providing replacement modules.

Accidental and Intentional Damage

- Individual modules may be damaged by vandalism, landscape maintenance activities, stray bullets, flying debris, wild animals, etc.
- Will be ongoing throughout the life of the plant.
- Modules replaced from inventory or suitable substitutes.

Extreme Weather, Fire, Flooding

- Hail, fire, wind, and flooding beyond the engineered extremes may damage large portions of the plant.
- Hail damage has recently emerged as a major concern for operators and insurers of plants located in hail prone regions. Tracker manufacturers are adding hail stow mechanisms as standard features and some module manufacturers are offering modules with increased glass thickness to reduce damage risk, but the industry has not yet developed technical solutions to effectively mitigate hail risk.
- Large-scale damage would likely require rebuilding large areas.
- Sufficient modules would not be expected to be in inventory and repowering with current market modules is likely required. Including modifications or replacement of racking systems to accommodate replacement modules.

PROCUREMENT TIME FRAME

For most solar projects, spare module requirements are estimated during the design phase and spares are ordered with the modules needed for the project. This is convenient as it allows the cost to be wrapped into the total capital outlay and modules are all exact matches for those incorporated into the operating project. However, in the case of a large project, it may be preferable to place a secondary order with the manufacturer after the project is fully operational, with an initial order quantity sufficient for shipping/installation breakage allowance and defective modules. So long as the modules will remain in production and the manufacturer can supply them, delaying the order has the advantages that all the modules can be budgeted as replacement spares for the operating phase of the project. It also avoids the need to have containers of spare modules sitting on the job site unneeded during construction, which then requires relocation to a storage area after final completion. For example, a project with 800,000 modules and a 1% spares allowance would require nearly 12 full shipping containers to be stored on-site during and after construction.

PROJECT LOCATION

Project designers and module manufacturers do not typically consider location when estimating equipment failures. Most of the materials incorporated into modules are engineered to tolerate moisture, temperature extremes, salt air, dust, mechanical stresses, etc., that are unique to the project location. However, some characteristics specific to a site can and will increase module degradation and failure rates. These should be considered with respect to the initial spares inventory and the long-term maintenance strategy Modules are tested by respected laboratories and rated for their resistance to various types of stress and degradation. Reviewing test reports and ratings will aid in selecting the best modules for a given site and in planning for replacements.

- Thermal extremes in hot, sunny climates put electrical and mechanical stresses on the module materials that will accelerate degradation and increase failure rates. In a large solar field, the modules located on the leeward side of the field will endure consistently higher temperatures than those on the windward side and will degrade at a higher rate.
- Thermal cycling in extremely hot and cold climates will stress individual module materials and module assemblies.
- Steady high winds and gusting wind locations will see better module cooling but greater flexing and vibration. Extreme winds, though infrequent, will flex modules and degrade brittle cell material.
- High snow loads may accumulate in some climates and place large mechanical loads on the module assemblies. Tracking arrays are typically designed to avoid snow accumulation via a “snow shake” algorithm in the controls system.

OWNERSHIP TIME FRAME

Developers and owners who intend to resell a project shortly after final commissioning or within the first years of operation will have a different view of spares. In this case, the objective is likely to have sufficient quantity to maintain the project fully operational through the holding period and to turn it over in good operating condition. This allows a new owner to implement their own long term operations and maintenance plan. A developer planning for long-term ownership, by contrast, will likely wish to procure ample spares consistent with the long-term operating plan for the project.

ECONOMIC CONSIDERATIONS

The economic value of maintaining high plant production must be balanced with the material and labor cost of detecting and replacing failed or underperforming modules. Each project has unique economics that derives from the terms of the power purchase agreement, tax rates, federal and municipal subsidies, the overall efficiency of monetizing tax subsidies within the capital structure, etc. Plans for spares procurement and storage must be evaluated within the unique economic context of the project.

SUMMARY

Many factors influence the appropriate quantity of excess modules that might be ordered to supply a specific project. Some factors will be common to all projects, regardless of module type, quality, scale, or location.

These are:

1. Breakage during shipping, handling, and installation. (Moderate quantity required)
2. Defective modules or those that have unseen damage and are not functioning correctly. These are typically detected during functional testing and commissioning and must be replaced prior to final completion. (Low quantity required)
3. Failures during the early years of operation due to invisible damage or defects can likely be replaced under warranty. (Low quantity required)

Once operational, modules will degrade slowly, with some failures detected and replaced during regular inspections and service. These quantities often are affected by the unique features of the project site.

1. Damage by vandalism, projectiles, flying debris, or other external means.
2. Damage caused by landscape maintenance activities.
3. Accelerated module failures caused by climate or weather events.

Finally, it is difficult to anticipate long-term failure rates because module technology has evolved rapidly and continues to do so. Module reliability and durability are both improving continuously. Experience with past failures, particularly from projects more than 10 years old, does not provide a particularly good reference for projecting future failure rates when it can be expected that the failure rates should be lower. For many years, module manufacturers have provided performance warranties exceeding 20 years, but this has not guaranteed performance and in many cases, the original manufacturers have ceased operations and do not support the warranties. Considerations related to modules themselves are:

1. Module technology and type.
2. Manufacturer quality.
3. Standardized test report data and ratings from independent laboratories.

As a matter of practice, spare modules for commercial and distribution scale solar facilities are ordered with the initial module supply. In cases of multiple projects are being supplied under a single master supply agreement (MSA). In this case, replacements are typically taken from existing stock, including those purchased for future projects still under development. Estimating the spares quantity for the operational phase is often imprecise, usually just consisting of those left over from construction. Spares may be stored on-site or nearby for quick access by O&M personnel.

For utility-scale projects, modules are typically ordered under a supply agreement specifically for the project and the developer often has the option to place a follow-up order to replace damaged and broken modules after the project is operational. Placing a second order has the advantage of purchasing spare modules while the original modules are still in production, and the number of spares can be planned more precisely. For a large project, the spares may amount to multiple containers that must be stored on-site or at a nearby secure storage facility. Having ample spares of the same model and bin class allows the operator to maintain high plant performance for longer and delays the time when modules must be replaced with alternates or when the plant may need a staged repowering.

About the author: **Daniel Tarico** is Director of Renewables, supporting E3's solar and energy storage practices. He has more than 17 years of design, construction, and operations experience in Utility Solar power and the C&I solar market. His insights into renewable infrastructure projects are guided by his knowledge of Finance, Engineering, and Construction, his long tenure in the space, and the breadth of his experience and education. Before entering the solar industry, Mr. Tarico held varied roles in technology development/industrial R&D and has nearly 25 years of total experience managing, working in, and continually improving construction projects of many types. He holds an M.B.A., with an emphasis on Finance and International Management, a M.S. in Materials Science, and B.S. in Metallurgical Engineering from the University of Arizona. For additional information about E3's solar practice and how we can support your project, please contact **daniel. tarico@e3co.com** or **602-510-3967.**