PV plant design and SCADA programming

Monitoring | The optimal incorporation of SCADA systems into a PV power plant can have a significant bearing on the profitability of a project. Marcos Blanco looks at how the layout and design of a PV system can best be configured to optimise a project's performance

Underperformance is a major contributing factor to the financial losses that PV plants frequently experience. PV plants are designed so that PV modules form into arrays, serially connecting tens of panels (depending on the park size), and if just one of the PV modules is underperforming this can have a negative effect on the park as a whole. Establishing effective monitoring systems to prevent such issues having long-term effects is one of the principal challenges faced by asset owners.

SCADA (supervisory control and data acquisition) systems are generally deployed to measure PV output, and detect any problems. However, solar plants can range from hundreds of kilowatts to tens of megawatts, and the larger the PV plant is, the more difficult it is to monitor what's happening several hectares away. The layout and design of a PV plant as well as effective SCADA programming play crucial roles in optimising solar projects.

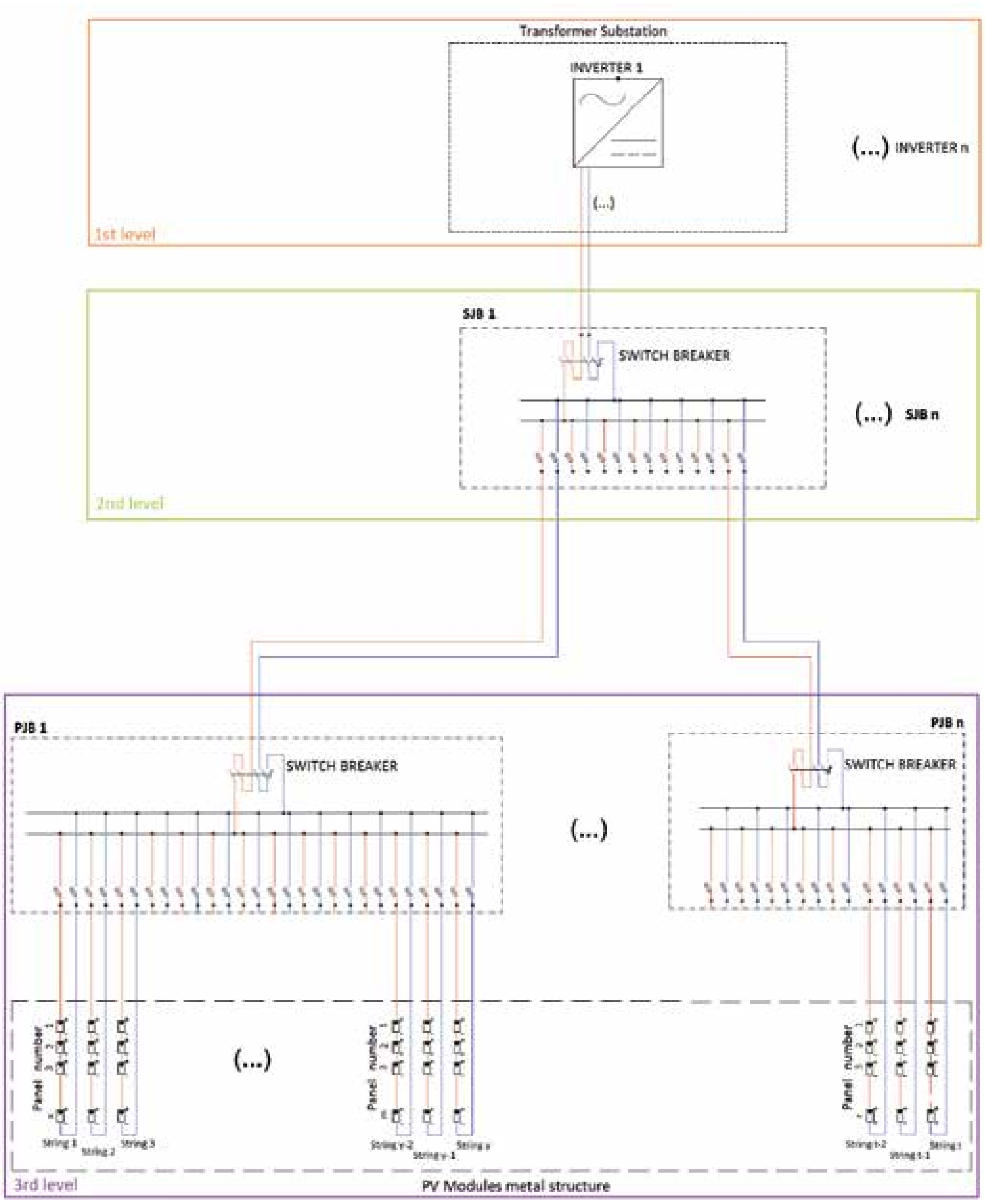
PV plant design

Modern PV plant designs operate on three levels, as shown in Figure 1. On the third level there are serial junctions of arrays, where the number of the serial junctions depends on the open circuit voltage (VOC) of the PV panel and the maximum DC voltage, conditioned by the chosen inverter model to ensure that it is always performing at the maximum power point (MPPT). The balance between power plant size, the maximum output power of the chosen inverter model and the input current of the corresponding transformer must be taken into account here.

The correct configuration of SCADA equipment within a PV power plant helps reduce the impact of power losses.

The second level is for the junction of PV panel arrays with its corresponding shelter, protections, sensors and communication modules. The inverters, transformers, line protections and meter(s)

Credit: SunEdison



▲**Figure 1: Typical PV power plant design.**

are located on the first level.

Frequently something will happen to one PV panel that will go unnoticed for several weeks if there aren't enough sensors installed for comparing defective currents with their neighbours. This problem is made worse during cloudy weeks when panels are not performing at 100% anyway, making real defects harder to spot. Figure 2 shows some of the main causes of loss in a PV power plant.

If a problem relates to a string of cells in a module, one could lose around 1.5 Amperes (in PV models with six rows of 10 cells), which would limit the value of the whole array in which the panel is located.

If the problem relates to the entire module, it will automatically short-circuit thanks to the bypass diodes installed in every PV panel, decreasing not only its power contribution but also its voltage contribution to the inverter input voltage.

Since it is virtually impossible to measure each primary junction box (PJB) by hand, it is essential to have sufficient sensors installed so as to be informed immediately when there is any problem with a module.

Of course, a balance has to be struck between design/construction costs and extensive monitoring devices. From a technical point of view, it is important to install as many differential current/voltage sensors as possible at the lower level to measure and compare the behaviour of neighbouring arrays, in order to program alarms into SCADA. This is essentially the only way to detect abnormal behaviour in solar plants.

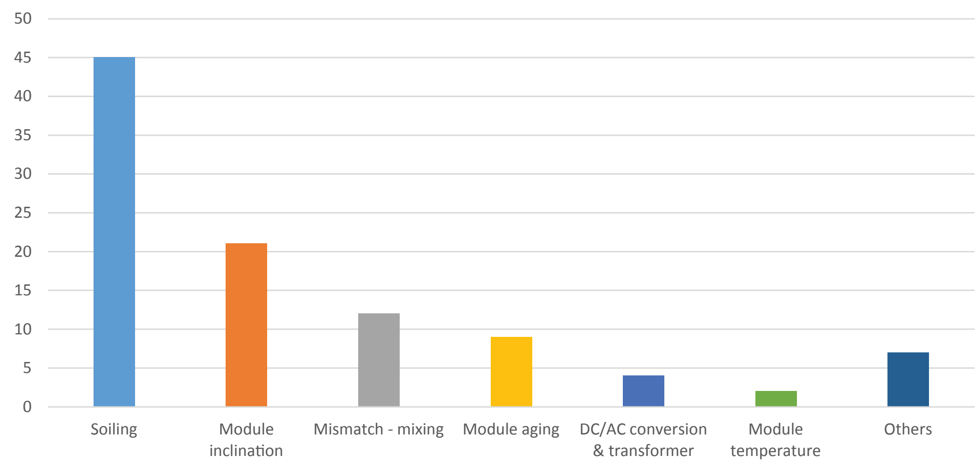
From an economic point of view, however, things aren't quite so straightforward. On the one hand, consistent and extensive monitoring can optimise park performance, and minimise expenses relating to technical issues and downtime. On the other hand, the cost of installing enough high-tech devices to achieve this is often very high.

In tbles 1, 2 and 3 there are examples of loss estimations in cases where defects have not been detected, based on several scenarios. All three estimations are based on a PV power plant of 1MW constructed with 60 cells monocrystalline modules and 250Wp, during an operation period of 20 years.

Improvements in typical PV power plant designs

There are a number of ways to optimise a park's performance which shouldn't break the bank. From a cost-efficiency perspective, outlined below are some pointers on how to use plant designs and SCADA programming to one's advantage.

▼**Figure 2: Percentage weighting of the main causes of loss in a PV power plant.**



Explotation period (years)	Device damaged / induced default	Irradiation per week during the problem exists (kWh/m²)	PRODUCTION per week without default (kWh)	Frequency of the problem (times/month)	Duration of the problem until it's discovered and fixed (in weeks)	PRODUCTION LOSSES per month (kWh)	PRODUCTION LOSSES per year (kWh)	PRODUCTION LOSSES during explotation (kWh)	PRODUCTION LOSSES during explotation (€)
20	"1 string (limitation of the current of the 14 PV modules array to 6,8Amperes) "	25	20986.9	1	1	7.0	84	1679	625
					2	14.0	168	3359	1250
					3	21.0	252	5038	1875
				2	1	14.0	168	3359	1250
					2	28.0	336	6718	2500
					3	42.0	504	10077	3751
				3	1	21.0	252	5038	1875
					2	42.0	504	10077	3751
					3	63.0	756	15115	5626
	"1 module (decreasing of the working point of the inverter -> reducing of the input current) "			1	1	20.0	240	4797	1785
					2	40.0	480	9594	3571
					3	60.0	720	14391	5356
				2	1	40.0	480	9594	3571
					2	80.0	959	19188	7142
					3	119.9	1439	28782	10713
				3	1	60.0	720	14391	5356
					2	119.9	1439	28782	10713
					3	179.9	2159	43173	16069
	"1 array (decreasing of the working point of the inverter -> reducing of the input current)"			1	1	28.0	336	6716	2500
					2	56.0	672	13432	4999
					3	83.9	1007	20147	7499
				2	1	56.0	672	13432	4999
					2	111.9	1343	26863	9998
					3	167.9	2015	40295	14998
				3	1	83.9	1007	20147	7499
					2	167.9	2015	40295	14998
						251.8	3022	60442	22497

◄**Table 1: Estimation of losses in a cloudy scenario.**

Explotation period (years)	Device damaged / induced default	Irradiation per week during the problem exists (kWh/m²)	PRODUCTION per week without default (kWh)	Frequency of the problem (times/month)	Duration of the problem until it's discovered and fixed (in weeks)	PRODUCTION LOSSES per month (kWh)	PRODUCTION LOSSES per year (kWh)	PRODUCTION LOSSES during explotation (kWh)	PRODUCTION LOSSES during explotation (€)
20	1 string (limitation of the current of the 14 PV modules array to 6,8Amperes)	50	41973.8	1	1	14.0	168	3359	1250
					2	28.0	336	6718	2500
					3	42.0	504	10077	3751
				2	1	28.0	336	6718	2500
					2	56.0	672	13436	5001
					3	84.0	1008	20154	7501
				3	1	42.0	504	10077	3751
					2	84.0	1008	20154	7501
					3	126.0	1512	30231	11252
	1 module (decreasing of the working point of the inverter -> reducing of the input current)			1	1	40.0	480	9594	3571
					2	80.0	959	19188	7142
					3	119.9	1439	28782	10713
				2	1	80.0	959	19188	7142
					2	159.9	1919	38376	14284
					3	239.9	2878	57564	21425
				3	1	119.9	1439	28782	10713
					2	239.9	2878	57564	21425
					3	359.8	4317	86346	32138
	1 array (decreasing of the working point of the inverter -> reducing of the input current)			1	1	56.0	672	13432	4999
					2	111.9	1343	26863	9998
					3	167.9	2015	40295	14998
				2	1	111.9	1343	26863	9998
					2	223.9	2686	53726	19997
					3	335.8	4029	80590	29995
				3	1	167.9	2015	40295	14998
					2	335.8	4029	80590	29995
					3	503.7	6044	120884	44993

◄**Table 2: Estimation of losses in a mixed scenario – 50% cloudy, 50% sunny.**

PV panels' electrical characteristics are measured by manufacturers at standard conditions (1,000W/m²; 25°C; 1,5AM). Under these conditions, solar panels must produce a certain amount of energy.

Since a PV panel's performance is dependent on irradiation levels, which are rarely constant, it can be difficult to gauge if a plant is producing enough power or not.

To find this out, several devices should be installed in each string (serial connections of PV panels) but since PV plants are composed of hundreds to thousands of strings, costs can spiral during construction.

To avoid faults regarding strings, we would recommend that differential current sensors are installed for each array on the third level (PJB). With differential current sensors one is able to measure the current value in each string at any given time. By using these measurements in SCADA comparisons, values from each string can be compared to the values of neighbour strings, which are exposed to similar irradiation levels, in order to detect faulty strings.

Modern PV plants are normally designed like this because current sensors for measuring 1.5A (in the case of thin-film modules) or 10A (in the case of crystalline modules) are relatively inexpensive.

Common faults with modules can be solved by installing differential voltage sensors at each array on the third level (PJB). When there is a problem related to a PV module as a whole, string current value is normally not affected (thanks to the module bypass diodes) but the voltage of the array is lower. Unfortunately inverters only start functioning at a certain voltage value and if the voltage value is not high enough, the inverter will experience periods of inactivity.

With voltage sensors at string level one would be able to measure voltage value in each string. Comparing measured values of the neighbour strings, we could easily detect strings with damaged modules.

This is normally not done in modern designs because voltage sensors for measuring from 500 to 800V DC (depending of the number of PV panels serially connected) are relatively expensive and installing them in each string represents a considerable increase of costs, so it must be evaluated before including it in the construction.

When it comes to complications with arrays, the best way to ensure they're dealt with quickly and simply is to replace the traditional fuses in each array with micro-breakers which have digital outputs that transmit any faults directly to the SCADA.

When the problem is related to an array, its current contribution to the power generation of the inverter is lost.

Normally there is a fuse installed at the beginning of the string (in the PJB), but if the fuse is melted, due to a PV panel malfunctioning, or if installed current or voltage sensors aren't installed, problems will go unnoticed. If micro breakers with a digital output are substituted for fuses, SCADA will be notified of the failure in the same moment that the breaker trips. On the other hand these devices need 12/24V DC power supply, so this will also significantly increase construction costs.

It is also crucial that SCADA is programmed properly. If sensors are all installed in the correct places, but SCADA isn't programmed to pick up their responses, then time and money can be lost.

▼**Table 3: Estimation of losses in a sunny scenario.**

Explotation period (years)	Device damaged / induced default	Irradiation per week during the problem exists (kWh/m²)	PRODUCTION per week without default (kWh)	Frequency of the problem (times/month)	Duration of the problem until it's discovered and fixed (in weeks)	PRODUCTION LOSSES per month (kWh)	PRODUCTION LOSSES per year (kWh)	PRODUCTION LOSSES during explotation (kWh)	PRODUCTION LOSSES during explotation (€)
20	1 string (limitation of the current of the 14 PV modules array to 6,8Amperes)	75	62960.6	1	1	21.0	252	5038	1875
					2	42.0	504	10077	3751
					3	63.0	756	15115	5626
				2	1	42.0	504	10077	3751
					2	84.0	1008	20154	7501
					3	126.0	1512	30231	11252
				3	1	63.0	756	15115	5626
					2	126.0	1512	30231	11252
					3	188.9	2267	45346	16878
	1 module (decreasing of the working point of the inverter -> reducing of the input current)			1	1	60.0	720	14391	5356
					2	119.9	1439	28782	10713
					3	179.9	2159	43173	16069
				2	1	119.9	1439	28782	10713
					2	239.9	2878	57564	21425
					3	359.8	4317	86346	32138
				3	1	179.9	2159	43173	16069
					2	359.8	4317	86346	32138
					3	539.7	6476	129519	48207
	1 array (decreasing of the working point of the inverter -> reducing of the input current)			1	1	83.9	1007	20147	7499
					2	167.9	2015	40295	14998
					3	251.8	3022	60442	22497
				2	1	167.9	2015	40295	14998
					2	335.8	4029	80590	29995
					3	503.7	6044	120884	44993
				3	1	251.8	3022	60442	22497
					2	503.7	6044	120884	44993
					3	755.5	9066	181327	67490

Concept	Extra cost of installation (£)
Differential current sensors	2,300
Differential voltage sensors	16,970
Micro breakers (instead of fuses)	8,270
DC power supply & communication modules (to be able to install sensors in each array)	2,760
Surge arresters	4450

▲Table 4: Extra costs for installing proposed solutions.

In order to detect underperformances, it is important to have full access to the information provided by sensors through the programming of SCADA with corresponding alarms. It is highly recommended that SCADA is programmed so as to have total control over the inverters.

In this way one is always ready for commands from the transmission system operator, or in potentially dangerous situations the device or plant can be stopped altogether. This ensures minimum damage to devices and can avoid subsequent problems with insurance policies.

As part of this, SCADA should take into account not only the closer arrays (with similar irradiation index, possible shadows, etc.) but all the similar constructed arrays.

To simplify the process, similar current panels can be installed into the same row. The organisation of PV panels into similar current values (regarding their maximum output power point) is a key element involved in the initial construction of a PV plant.

The arrangement of PV panels should also be considered during periods of maintenance when a defective panel is replaced by a new one.

Avoiding mixing panels of a different current ensures that losses, which can result from the limitation of one lower current panel installed in the row, are kept under control. If mixing of panels is not avoided, such losses could represent the main performance loss after soiling, which normally represents the first cause.

Costs versus benefits

The recommendations made in this piece are not absolute. Each park is different and there are always exceptions that need to be taken into account. Table 4 below shows the associated extra costs to a 1MW PV power plant of installing the proposed solutions:

If we consider the production losses (Table 5) and then consider the extra costs (Table 4), we will see that in many cases it would be more profitable to install the recommended devices than to manage the difficulties that can result from their absence on a PV plant.

Furthermore, in Table 5, production losses only consider the "optimistic" case (i.e that the problem will only occur in one of the 10 inverters (arrays) that the 1MW plant contains). In reality, problems would normally appear in more than one and, the larger the installation is, the higher the probability is that that number will increase.

Given these results, it is highly recommended that during the due diligence process the investors of a PV plant carry out a serious study involving several economic scenarios. At least two, if not three, possible design options should be considered. This should help managers to discover the ideal configuration/design for the maximum efficiency and profitability of their PV plants. ■

▼Table 5. Summary of production losses and profitable cases .

Operation period (years)	Device damaged / induced default	Frequency of the problem (times/month)	Duration of the problem until it's discovered and fixed (in weeks)	Cloudy scenario (€)	Mixed scenario (€)	Sunny scenario (€)
20	1 string (limitation of the current of the 14 PV modules array to 6,8Amperes) Equ losses of 0,83%	1	1	625	1250	1875
			2	1250	2500	3751
			3	1875	3751	5626
		2	1	1250	2500	3751
			2	2500	5001	7501
			3	3751	7501	11252
		3	1	1875	3751	5626
			2	3751	7501	11252
			3	5626	11252	16878
	1 module (decreasing of the working point of the inverter -> reducing of the input current) Equ losses of 2,38%	1	1	1785	3571	5356
			2	3571	7142	10713
			3	5356	10713	16069
		2	1	3571	7142	10713
			2	7142	14284	21425
			3	10713	21425	32138
		3	1	5356	10713	16069
			2	10713	21425	32138
			3	16069	32138	48207
	1 array (decreasing of the working point of the inverter -> reducing of the input current) Equ losses of 3,33%	1	1	2500	4999	7499
			2	4999	9998	14998
			3	7499	14998	22497
		2	1	4999	9998	14998
			2	9998	19997	29995
			3	14998	29995	44993
		3	1	7499	14998	22497
			2	14998	29995	44993
			3	22497	44993	67490

Author

Marcos Blanco has worked as an operations and maintenance engineer for Greensolver since the beginning of this year. He is responsible for the optimisation of renewable energy projects, covering maintenance, insurance and health and safety for each of them. He has over 10 years' experience in the engineering sector, including project manager and quality engineer roles. He has a degree in electric engineering, and an MBA from Valladolid University.