TECHNICAL PAPER:

TERRAIN ADAPTABILITY AND STRUCTURAL SHADING ON BI-FACIAL MODULES BACKSIDE

GP JOULE PHLEGON® SERIES
3 LANDSCAPE | HORIZONTAL VS. 1 PORTRAIT | VERTICAL

By

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Site topography or the terrain is one of the major challenges that a tracker manufacturer faces everyday, and often viability of the tracker for a site is decided based on one very key component. Trackers can become difficult to install at grade exceeding ±5%, and typically require relatively flat site conditions. In addition, the recent rise in bi-facial modules requests made it imperative for traditional tracker manufacturers to have a compatible design available for maximum gains from the site existing Albedo (a proportion of light that is being reflected from the site landscape, which can vary anywhere between 5% to 80%).

This report aims to:

- identify adaptability of each tracker for various terrains (N/S direction only) with the associated material and installation cost,
- show preferable mounting structure for bi-facial modules by using geometric data from CAD models and by using PVSYST - a widely used software to confirm production differences for both orientations (portrait vs landscape).

1.Background and Analysis

1.1 Terrain Adaptability

Traditionally, a site topography or terrain can have a consistently increasing or decreasing slope going in any direction or may appear as a sine wave ranging anywhere from ±0% to ±20% or more. No matter how the slope is reported, to mitigate the increased friction between the steel components and miss alignments between the torque tubes, tracker undulations must be leveled within certain tolerances. There may be other effective ways of countering these issues on site, but they could end up proving to be counterintuitive and may not work effectively during construction. PHLEGON® 3L|1P Series (Image 1 and 2) relies on the following three key items to effectively counter those issues above in terms of form-fit function of the system and better balanced or "smoother" tracking experience.

1. Pile cap and its connection to the torque tube and pile.
2. Carrier plate with table gaps between the adjacent table (Non-continuous beams only e.g. PHLEGON 3L Series).
3. Minimum and maximum pile heights (final stick up height).

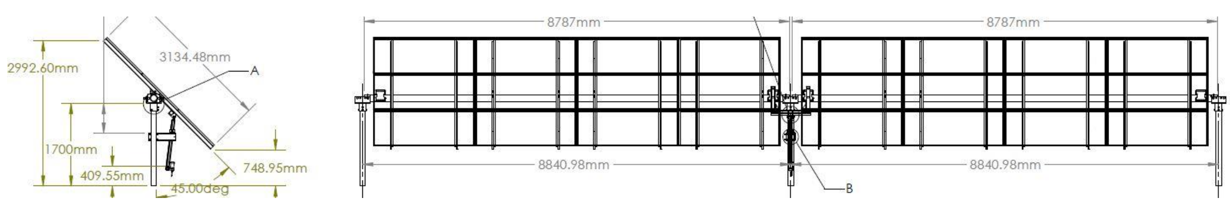

Image 1: Typical PHLEGON 3L Series Tracker.

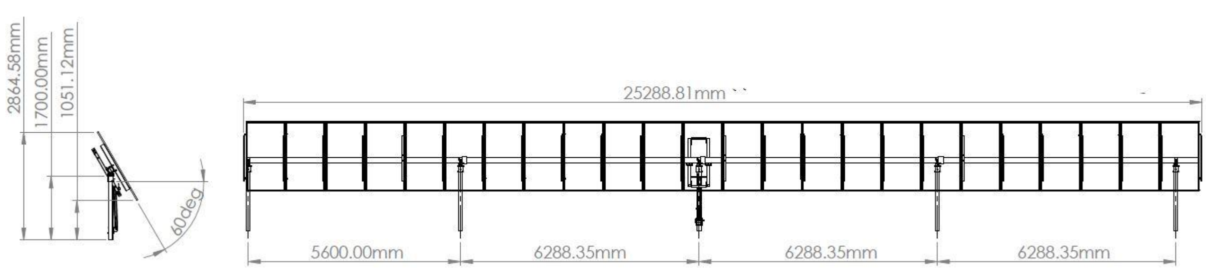

Image 2: Typical PHLEGON 1P Series Tracker.

1.1.1 Pile Cap

PHLEGON 3L|1P Series pile caps are designed to correct discrepancies in foundation installation (within their limited capacities, typically around 10mm all around or up to 3% to 5% correction limit) as shown in Image 3 below, even after piles have been cut to final heights. When installing the system on a sloped site, the objective is to achieve a constant slope along all the Main Beams of the tables within the same block of tables.

The Cap capacity to correct discrepancies is dictated by the gap between cap and the pile as shown in Image 4 below. The gap may need to be increased to provide additional tolerances in case the following controlled tolerances are not met due to the site's unforeseen underground conditions or obstructions i.e., deflected piles due to boulders or other non-moveable buried objects. The finished height and orientation of the Pile Cap should be established by running a string line across the Pile Caps of a single block of tables and by staying within the pile installation tolerances as part of the minimum grade change requirements.

Pile Installation Tolerances:

- East/west ±50mm. north/south ±50mm
- 30mm of nominal height
- 60mm cut-off height variation from lowest/shortest pile relative to all piles of racking structure
- ±2° from plumb

Note: An option of modified pile cap is also available for out of tolerance and for out of place piles where remediation work is not possible.

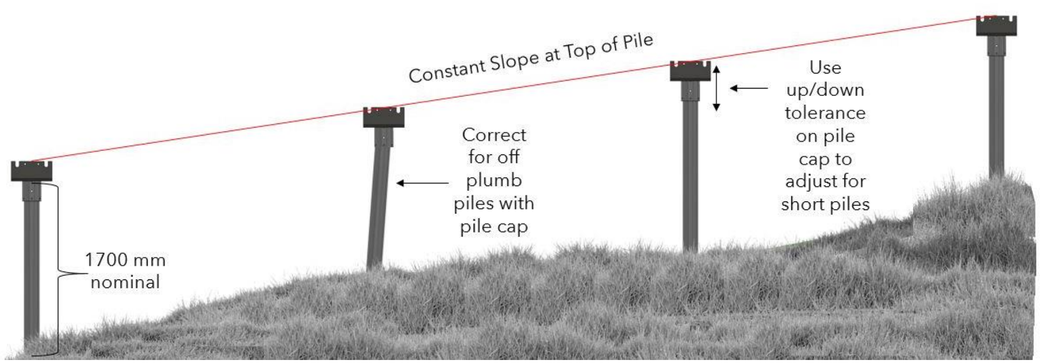

Image 3: Pile Cap Orientations to Facilitate Pile discrepancies.

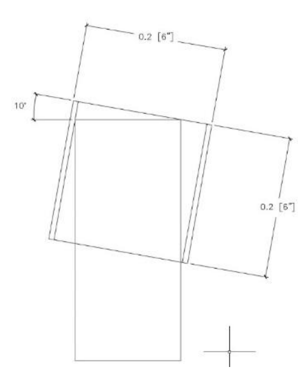

Image 4: Pile cap gap diagram illustrating maximum slope correction limit.

1.1.2 Carrier Plate

PHELGON 3L series is designed for the challenging terrains by using a unique connection between pile cap and the carrier plate. Currently this feature is only available for 3L series, and from experience GP JOULE has seen this feature often get overlooked at a first glance.

To form a consistent 10% - 25% slope without grading the pile cap bracket needs to be perpendicular to the main torque tube rotational axis. This is difficult to achieve because regardless of the plumbness of the foundation or the slope of the terrain, it is required that the Pile Cap is installed perpendicular to world, ensuring loads and forces are appropriately transferred throughout the system during operation.

Image 5 below shows how 3L series achieves that efficiently without causing interference to the other components. In addition, due to large tilts E/W plus the high N/S grade variations, the table to table gap may need to be larger in N/S direction as shown in Image 1 above.

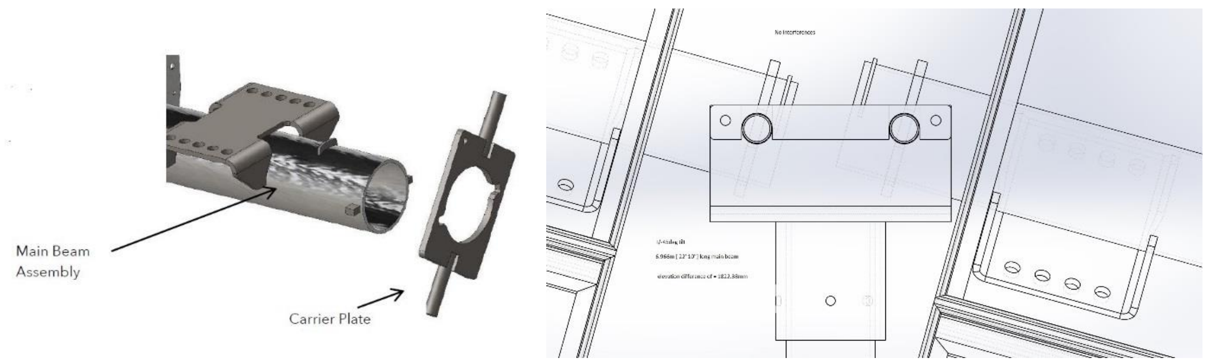

Image 5: Carrier plate installation and its application in service to accommodate 25% slope.

To adjust the tubes misalignment as shown above (Image 5), carrier plate geometry comes into play as shown in Image 6 below where the circular feature is centred at 3.63" above the geometric center of the plate. Once the Main Beam is staged and ready to be lowered onto the Pile Cap, the Carrier Plate Assembly can be oriented in the same configuration (HOLE ON TOP) for flat terrain, and an alternating orientation for a sloped terrain to maintain a constant Main Beam slope or alignment.

Note: small ½" hole at the top right corner of the plate works as a reference point to know how to orient the adject carrier plate.

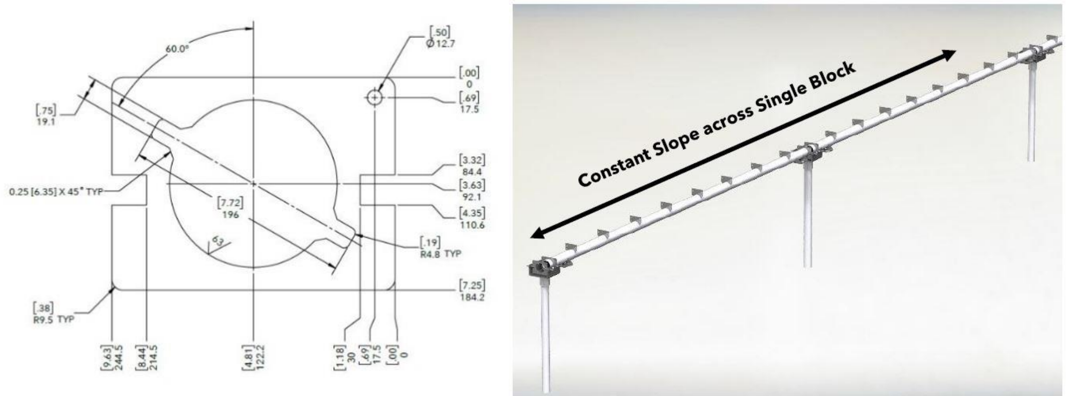

Image 6: Carrier plate detail and features.

1.1.3 Pile Heights

PHLEGON 3L|1P Series is available with different configurations also called block of bays or tables. PHLEGON 3L comes with blocks of 2|3|4 tables, and PHLEGON 1P comes with a 1 or 2-string table where a string can vary between 18 to 26 modules per string. A block of tables is defined as all tables or modules that are actuated with a single actuator, as shown in the Image 1 above. As previously mentioned, it is industry standard to either:

1) cut the piles, after pile installation, to their specific stick up heights, based on the slope studies
2) install the pile up to their designed final stick ups to avoid cutting or welding later, which achieves a constant slope and minimum clearance along all the tables' Main Beams within the same block of tables.

One or the other method is desirable but requires ideal soil and site conditions, including ground penetrations without the underground obstructions. With these restrictions, sites with slopes or unlevel terrain will require extensive grading and additional costs, which typically make trackers less economical.

Keeping these restrictions in mind, PHLEGON 1P trackers is at a slight disadvantage in terms of maintaining minimum to no grading or clearance above the native grade compared to PHLEGON 3L. This is primarily because of the longer continuous torque beams that span between 25m to 50m along the grade for 1P series versus 17m - 34m spans for 3L series. In addition, these issues can increase engineering time, and would generate more work for on-site adjustments. Images below, taken from an Ontario, Canada test site, compare flexibility of the two trackers side by side.

From the top of the pile analysis below (image 7), 3L handles terrain variability more efficiently compare to 1P. In fact, 3L would require only one extension to be added on later to finish the block of three tables with their tubes sitting concentric to each other compared to 1P, which would need four extensions instead of one to finish the assembly. In addition, it is also conclusive that smaller to larger configurations of 2|3|4 tables makes 3L even more flexible compared to 1P as a 3L table would need 8.5m to fit 12 modules versus 1P which would need 12m.

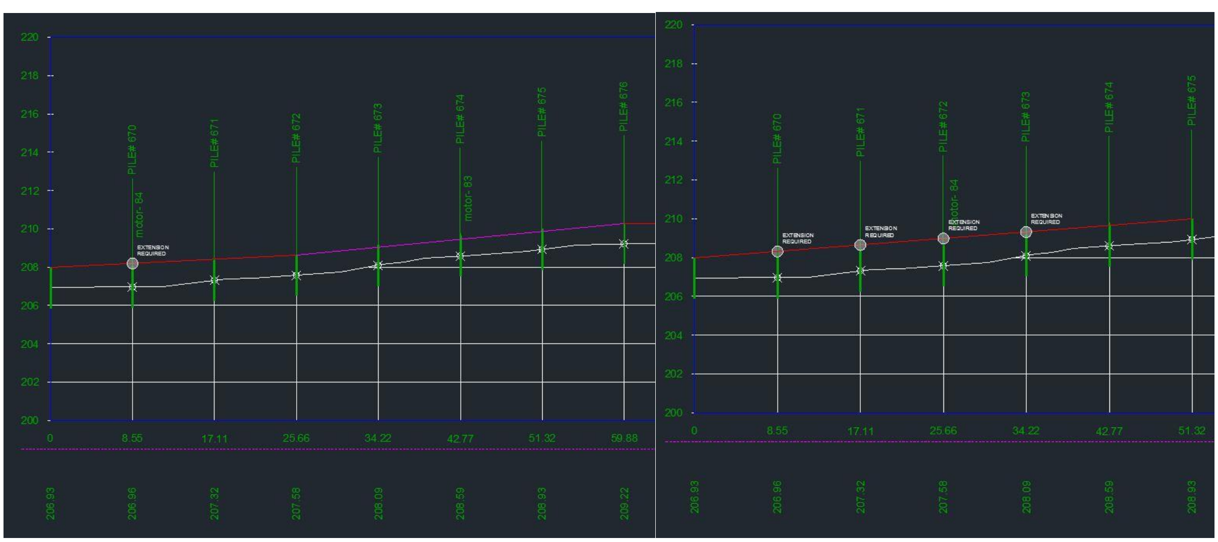

Image 7: Top of the pile analysis 3L (Left) and 1P (Right).

1.2 Structural Shading Comparison for Bi-facial Gains:

Bi-facial modules produce solar power from both sides of the modules, and bi-facial system design requires new approaches for potential improvements to achieve maximum gains from them. Recent studies have been conducted on optimal mounting configuration for bi-facial modules, making traditional trackers sub-optimal. Out of the three mounting configurations in Image 8 below, the "2 Vertical" portrait module mounting configuration is the preferred option to get maximum gain from bi-facial modules. With the increase size of module frames to facilitate reductions in material and installation costs, the table "sizes" or heights to carry these larger products is increasing significantly to 4.5 to 4.8 meters if a space or a gap is created between the modules to prevent the torque tubes to obstruct fully the back side of the bi-facial modules. The ability to operate single axis trackers with 2 module Vertical with such larger table sizes or heights in the Northern markets (Canada, Northeast US, Midwest US) are becoming uneconomical on a cost per kWh basis looking at the increased racking steel parts or increased thicknesses, piles and associated costs and the additional actuators, shock absorbers, and associated controls to maintain a structurally sound system with as much up time as possible (due to snow, wind and frost jacking loads). It is of GP JOULE opinion that 1P and 3P trackers are the optimal solution to ensure reliable returns and the lowest cost of energy in Northern markets.

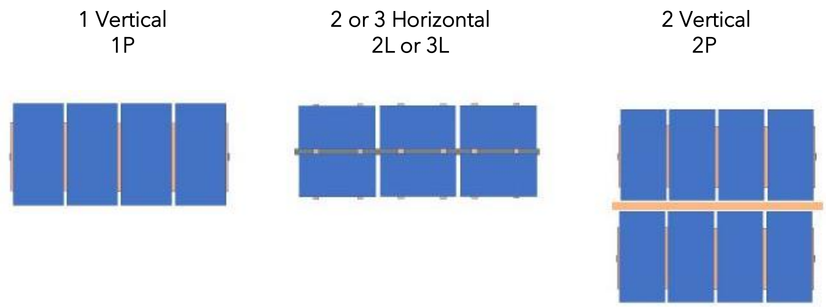

Image 8: Preferred Mounting Configuration for Bi-facial Modules.

Developer and module manufacturer's recent studies conclude: To achieve higher bi-facial gains, trackers should be deployed at sites with ideal Albedo conditions, including higher ground clearances, and higher row spacings.

With their ability to have higher ground clearances of about 900mm to 1200mm or more, and modules mounted at 6.5 inches away from the main beam or torque tube (Image 10) for better Albedo absorptions, we can fairly assume that PHLEGON® Tracker series will easily out perform its competitors in terms of better bi-facial gains. In addition, the shared pile system of 3L series (50/60 less piles compared to its competitors), a system where a pile is being shared between the two tables and the pile is placed right in the middle of table to table gap, will not add any additional obstructions compared to all other traditional systems, but in turn will help increase 1% to 2% gains to the overall production. The following analysis focuses only on the effects of production due to the obstruction areas on the rear side of 24 modules of 3L versus 1P, as shown in Image 9.

As per analysis below, differential of 1.78% was found between the two racks, meaning 3L has 1.78% additional obstruction areas compared to the 1P. These estimated key inputs were used in PVSYST simulation to confirm the production difference. Scaled models based on the chord lengths' ratios were used for the following simulation to accurately compare detail parameters and results for both trackers; provided in images below (Image 11,12).

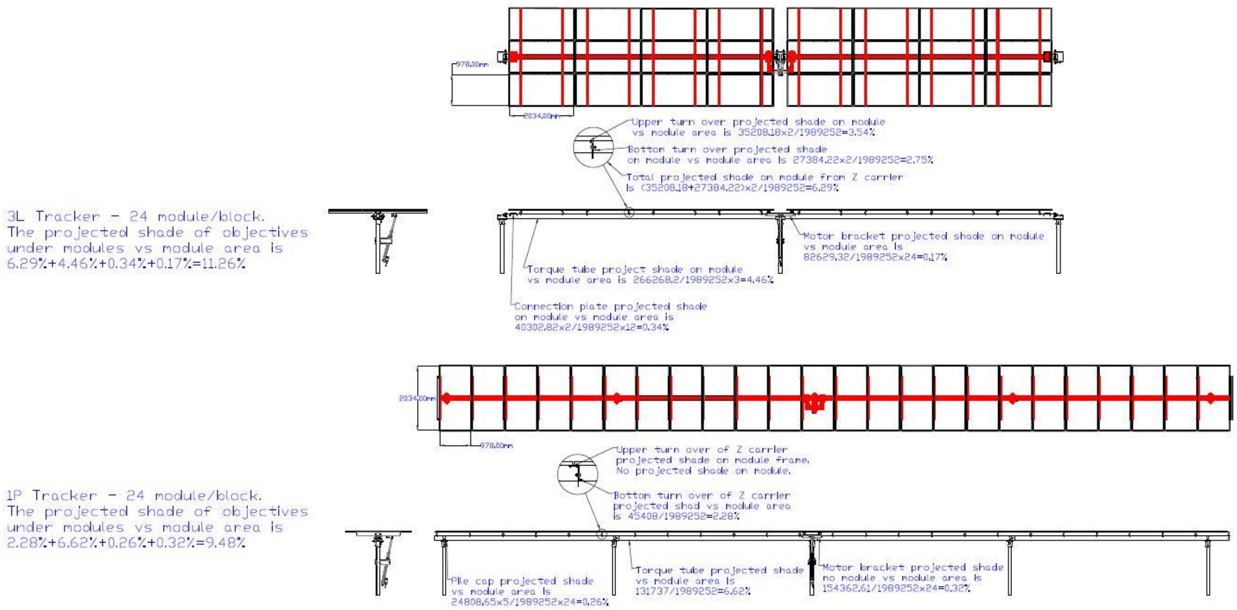

Image 9: Obstruction Areas on rear side of the 24 modules (3L has 11.26% and 1P has 9.48%)

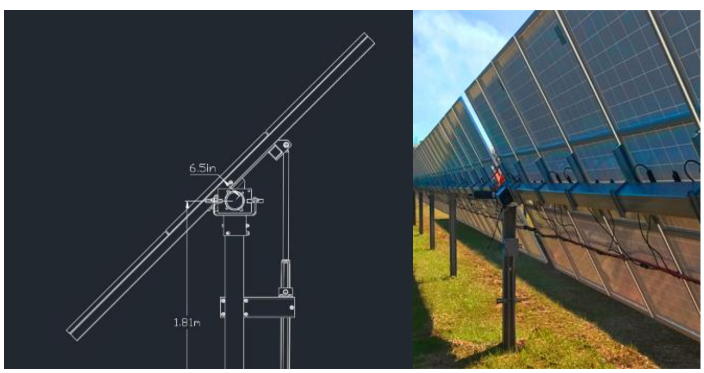

Image 10: PHLEGON® 3L Series and a Competitor Tracker Module Mounting

Simulation parameters	System type	**Trackers single array, with backtracking**		
Tracking plane, tilted axis	Axis Tilt	0°	Axis azimuth	0°
Rotation Limitations	Minimum Phi	-45°	Maximum Phi	45°
	Tracking algorithm	Astronomic calculation		
Backtracking strategy	Nb. of trackers	22	Single array	
	Tracker Spacing	15.0 m	Collector width	3.17 m
Inactive band	Left	0.02 m	Right	0.02 m
Backtracking limit angle	Phi limits	+/- 77.6°	Ground Cov. Ratio (GCR)	21.2%
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
			Circumsolar	with diffuse
Horizon	Free Horizon			
Near Shadings	Linear shadings			
Bifacial system	Model	, unlimited trackers 2D Calculation		
	Tracker Spacing	15.00 m	Tracker width	3.21 m
	Backtracking limit angle	77.6°	GCR	21.4 %
	Ground albedo	0.30	Axis height above ground	1.00 m
	Module bifaciality factor	70 %	Rear shading factor	11.3 %
	Module transparency	0.0 %	Rear mismatch loss	10.0 %
User's needs :	Unlimited load (grid)			

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	38.7	15.98	-10.16	60.2	55.9	91.5	85.9	0.949
February	59.2	22.56	-9.00	89.0	84.3	136.7	129.8	0.970
March	113.1	36.56	-2.36	170.3	163.5	255.5	243.5	0.951
April	150.4	48.06	5.05	218.2	210.2	314.2	299.2	0.912
May	185.2	78.27	11.26	253.2	243.1	359.1	342.7	0.900
June	195.8	71.06	15.52	268.5	258.5	370.6	353.5	0.876
July	211.3	63.86	20.45	298.5	287.9	406.3	387.7	0.864
August	175.6	53.42	17.92	248.2	239.4	341.3	325.2	0.871
September	117.6	38.57	12.17	174.2	167.4	247.0	235.3	0.899
October	78.9	29.98	4.94	117.0	111.4	171.5	163.1	0.927
November	41.7	17.63	-1.86	64.6	60.4	95.8	90.1	0.928
December	31.9	13.18	-10.23	52.2	47.9	78.4	73.3	0.934
Year	1399.3	489.13	4.55	2013.9	1929.8	2867.9	2729.3	0.901

Image 11: Main system results and Simulation parameters with 11.3% Rear Shading for 3L

Simulation parameters	System type	**Trackers single array, with backtracking**			
Tracking plane, tilted axis	Axis Tilt	0°	Axis azimuth	0°	
Rotation Limitations	Minimum Phi	-60°	Maximum Phi	60°	
	Tracking algorithm	Astronomic calculation			
Backtracking strategy	Nb. of trackers	22	Single array		
	Tracker Spacing	10.00 m	Collector width	2.15 m	
Inactive band	Left	0.02 m	Right	0.02 m	
Backtracking limit angle	Phi limits	+/- 77.3°	Ground Cov. Ratio (GCR)	21.5%	
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm	
			Circumsolar	with diffuse	
Horizon	Free Horizon				
Near Shadings	Linear shadings				
Bifacial system	Model	, unlimited trackers 2D Calculation			
	Tracker Spacing	10.00 m	Tracker width	2.19 m	
	Backtracking limit angle	77.3°	GCR	21.9 %	
	Ground albedo	0.30	Axis height above ground	1.00 m	
	Module bifaciality factor	75 %	Rear shading factor	9.5 %	
	Module transparency	0.0 %	Rear mismatch loss	10.0 %	
User's needs :	Unlimited load (grid)				

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	38.7	15.98	-10.16	62.0	57.7	96.4	90.6	0.972
February	59.2	22.56	-9.00	91.1	86.3	142.3	135.0	0.986
March	113.1	36.56	-2.36	174.4	167.2	264.5	251.9	0.961
April	150.4	48.06	5.05	223.0	214.6	322.0	306.4	0.914
May	185.2	78.27	11.26	257.7	247.0	368.4	351.5	0.907
June	195.8	71.06	15.52	272.4	262.1	378.0	360.5	0.880
July	211.3	63.86	20.45	304.1	293.1	415.8	396.6	0.868
August	175.6	53.42	17.92	253.4	244.1	350.0	333.4	0.875
September	117.6	38.57	12.17	178.4	171.4	255.0	242.8	0.905
October	78.9	29.98	4.94	119.8	114.0	177.8	169.1	0.939
November	41.7	17.63	-1.86	66.3	62.0	100.0	94.1	0.945
December	31.9	13.18	-10.23	53.3	49.0	81.7	76.4	0.954
Year	1399.3	489.13	4.55	2055.8	1968.5	2951.8	2808.3	0.909

Image 12: Main system results and Simulation parameters with 9.5% Rear Shading for 1P

Estimated production results above reveal that the GP JOULE PHLEGON 1P tracker performs marginally better by 0.8% compare to 3L purely based on rear shading obstructions which can be improved further pending detail shading and more in-depth analysis. Competitor trackers to GP JOULE in the 1P market, as shown in a typical example shown on Image 10, do not benefit from the extra 6.5'' spacing created by design to increase Albedo production.

From a Capex' perspective for projects with high foundation costs and risks, the 3P shows some significant savings and by carrying less piles 50/60% less piles than any 1P tracker in the market and torque beams as a percentage per module.

2. Conclusion:

GP JOULE aims to provide an overview of the two products in terms of how each handle challenging topographies and how each product performs slightly differently from each other based on rear module obstructions, giving some perspective on the overall cost per kWh. PHLEGON 1P tracker is very viable for relatively flat terrains but undulating and more challenging site topographies require robust tracking structures to be considered as an option. PHLEGON 3L series can accommodate up to 15% or more slope easily with minimal effort and very minor grading. The table below summarizes the capabilities of the various products. Furthermore, with its shared piles system, ability to mount 12 modules between piles, and its ability to transfer environmental loads under extreme conditions appropriately, makes 3L a better value once installed compared to 1P of competitors which require a lot more on site installation.

	Standard Slope[1]	Ability to Handle Slope Variability	Smallest Rise over Run (24String)
PHLEGON® 3L Series	up to 15% (8.5°)[2]	Yes (1 or 2 strings dense blocks)[3]	2m/16m
PHLEGON® 1P Series	up to 5% (3°)	No (grading required)	2m/25m
Other 1P Manufacturers	up to 5% (3°)	No (grading required)	2m/50m

[1] Piles assumed to be with same stick up at all locations

[2] PHLEGON® 3L series can achieve 15% (8.5°) slope by utilizing the adjustability provided by the carrier Plate assembly and pile cap designs. 1P series only relies on the gap between the pile cap and the round foundation pile to achieve 5% (3°) or by sliding the pile cap along the slotted connections on I-Beam.

[3] Only short spans of 3L series (16m-17m for single string) can accommodate 15% (8.5°) slope variability and can be improved further by adding an additional pile between the blocks for an extravagant N/S slope, increasing pile heights. 1P would require addition mechanical comments or shorter spans to accommodate 5% (3°) slope variability.

In terms of rear shading, a marginal 0.8% estimated production delta between the two GP JOULE products provides some background to comparing the GP JOULE products to other single axis tracking solutions available in the market, which are mostly part of the 1P group. 50/60% less piles compared to its competitors, piles placed between the array causing no obstructions to the rear side of the modules with potential of 1% to 2% more gains, and modules mounted 6.5 inches away from the main beam or torque tube, we can safely assume that 3L will out perform most of its competitors. It is important to mention that bi-facial gain estimates for long term analyses requires the use of representative albedo values throughout the period being analyzed. Bi-facial system design requires new approaches for potential improvements to achieve the maximum gains from the concept and should be deployed at sites with better Albedo conditions, with higher ground clearances, and higher row spacings.