Analysis and Verification of Algeria KAE 3MWp Solar Power Plant Electrical Capacity Calculation Report

Xiang Ye
International Department of STECOL, Sinohydro Tianjin Engineering Corporation Limited, Tianjin, 300384, China
YEXIANG@STECOL.CN

Abstract. The electrical capacity calculation report of Algeria KAE 3MWp Solar Power Plant is specifically analyzed and verified. The analysis results show that the EPC contractual and conceptional design is applicable and further optimization works is possible to be implemented during construction design stage, the technical requirements for both electricity production and PR values are confirmed within efficient ranges.

1. Introduction
This report is prepared for the overall 25 years designed life-time of the subject KAE 3MWp SPP, which is based on the following initial documentations: solar irradiation parameters, geological reports, electrical equipment’s technical catalogues and datasheets, poly crystalline silicon photovoltaic solar modules YL245P-29bYGE60, photovoltaic inverters SG500MX, NASA monthly average temperature data.

2. Power generation system configuration
The power generation system is constituted of 3 nos. 1MW sub-fields, each contains 1 set 1250/630/630kVA, dry type, three windings transformer (one MV winding, two LV windings), 2 sets centralized 500kW inverters; 4092 nos. 245Wp modules. Each inverter is connected to 4 DC input circuits continuously from of one separate Level-3 DC combination box, each Level-3 DC combination box is connected to 4 nos. DC parallel boxes, and each DC parallel box will be connected to 4 nos. DC junction boxes(in which, one junction box is reserved), each DC junction box is connected to 8 nos. PV module strings.

The subject SPP is connected to Algerian National Power Grid and its power generation system is made up of 3 levels of DC boxes, 2 inverters per 1MW sub-field, and a single 35kV outgoing OHTL.

| Table No.1 Project Input data: | UTC+1, Latitude 28.4N, Longitude 0.0W, Alti |
|-----------------------------|-----------------------------------------------|
| Hor. global                | Jan  3.63  4.59  5.75  6.77  7.19  7.57  7.46  6.93  5.99  4.74  3.73  3.24  5.64 |
| Hor. Diffuse               | Feb  1.15  1.46  1.91  2.08  2.39  2.51  2.48  2.28  2.04  1.66  1.31  1.13  1.87 |
| Extra terrestrial          | Mar  6.20  7.51  8.96  10.3  11.1  11.3  11.2  10.6  9.49  8.01  6.56  5.80  8.94 |
| Clearness Index            | Apr  0.58  0.61  0.64  0.65  0.64  0.66  0.66  0.65  0.631 0.59  0.56  0.558 0.63 |
| Ambient                    | May  11.7  14.6  18.8  23.4  28.3  33.3  35.7  35.2  31.4  25.2  18.4  13.2  24.1 |
Technical datasheets:

YL245P-29bYGE60 Poly Crystalline Silicon modules: STC power $P_{\text{nom}}=245\text{Wp}$, Size($W\times L$) =0.990×1.650m², 60 cells, Si-poly technology, 1.63m² rough module area, Model specifications $T_{\text{Ref}}=25^\circ\text{C}, G_{\text{Ref}}=1000\text{W/m}^2, V_{\text{oc}}=37.8\text{V}, I_{\text{sc}}=8.63\text{A}, V_{\text{mpp}}=30.2\text{V}, I_{\text{mpp}}=8.11\text{A}, P_{\text{mpp}}=244.9\text{W}$, $I_{\text{sc}}$ temperature coefficient $\mu_{\text{sc}}=5.2\text{mA/}^\circ\text{C}$,One-diode model parameters shunt resistance $R_{\text{shunt}}=300\text{ohm}$, Diode saturation current $I_{\text{Ref}}=2\text{nA}$, Serie resistance $R_{\text{serie}}=0.3\text{ohm}$,Diode quality factor $\Gamma_{\text{m}}=1.11$, Specified $P_{\text{max}}$ temp.coeff. $\mu_{\text{PmaxR}}=-0.45\%/^\circ\text{C}$, Diode factor temper.coeff. $\mu_{\text{Gamma}} -0.0001/^\circ\text{C}$,Reverse Bias Parameters for use in behaviour of PV arrays under partial shading or mismatch, Reverse characteristics (dark) $B_{\text{Rev}}=3.20\text{ma/V2}$ ( quadratic factor per cell),number of by-pass diodes per module 3, direct voltage of by-pass diodes = -0.7V, Model results for standard conditions (STC: $T=25^\circ\text{C}, G=1000\text{W/m}^2, \text{AM}=1.5$), Max. Power point voltage $V_{\text{mpp}}=30.4\text{V}$, Max. power point current $I_{\text{mpp}}=8.06\text{A}$, Max. Power $P_{\text{mpp}}=245.0\text{Wc}$, Power temper. Coefficient $\mu_{\text{Pmpp}}=-0.45\%/^\circ\text{C}$, Efficiency/(Modular area) $\text{Eff}_{\text{mod}}=15.0\%$, Fill factor $\text{FF}=0.751$.

![Chart 1](chart1.png)

Chart 1. Characteristics Curve of YL245P-29b and Input Power/Efficiency Curve of SG500MX

Sungrow SG500MX operating mode MPPT, Minimum MPP Voltage $V_{\text{min}}=500\text{V}$, Maximum MPP voltage $V_{\text{max}}=850\text{V}$, absolute max.PV voltage $V_{\text{max}}$ array 1000V, Behaviour at $V_{\text{min}}/V_{\text{max}}$ limitation, Nominal PV power $P_{\text{nom}}\text{ DC 507kW}$, Maximum PV power $P_{\text{max}}\text{ DC 600kW}$, Power threshold $P_{\text{thresh}}=2500\text{kW}$, Behaviour at $P_{\text{nom}}$ Limitation, Output characteristics (AC grid side) Grid voltage $U_{\text{nom}}=315\text{V}$, Grid Frequency 50/60Hz, Triphased, Maximum efficiency 98.8%, European average efficiency 98.5%, Nominal AC Power $P_{\text{nom}}\text{ AC 500kWac}$, Maximum AC power $P_{\text{max}}\text{ AC 500 kWac}$, nominal AC current $I_{\text{nom}}\text{ AC 917A}$, Maximum AC current $I_{\text{max}}\text{ AC 1100A}$, Sizes Width 2200mm, Height 2180mm, Depth 850mm, Weight 2000kg, technology without transfo, IGBT, IP20(Indoor) protection , Touch Screen control.

The total peak power can reach up to 3008 kW.the range of voltage of the service continuously is from 500V to 850V. In STC, $V_{\text{mpp}} = 30.2\text{V}$, the temperature factor for $V_{\text{mpp}}$ is -0.45% / ^\circ\text{C}, At maximum temperature of 60 ^\circ\text{C}, $V_{\text{mpp}} = 25.3\text{V}$; at minimum temperature -10 ^\circ\text{C}, $V_{\text{mpp}} = 42.7\text{V}$.

The number of modules on a channel is determined in function of the voltage maximum input and the minimum operating voltage of the inverter, the result of calculations performed by software shows that the number of modules is between 20 and 23, the number 22 for a string of PV modules is determined. The rated power of a string of PV modules is $22 \times 245\text{Wp} = 5,39kWp$.

The number of parallel strings is determined depending on the rated capacity of the inverter, the number of strings in parallel for each inverter of 500kW / 5,39kWp ≈ 93, the total number of strings for KAE 3MWp SPP is 558 nos.
3. Array Arrangements,
Selection of orientation angle: the photovoltaic modules will be installed on a fixed load-bearing structure, oriented at an azimuth of 0°. Selection the optimum tilt angle: for the photovoltaic generator system connected to the network, the angle of inclination is defined by a principle which allows a radiation maximum on the face inclined photovoltaic fields for an annual period. It can receive radiation maximum in tilting the modules with an angle of 28°, a coefficient of conversion TF = 1.10, is the annual maximum deliverability.

Determining the spacing between the rows of strings: the spacing is ideal (that is to say which allows to maximize the output annual) between each row of modules has been determined with the help of software. This software includes algorithms that take into account the course of the sun every day of the year and that some or the location of the site as well as the pattern layout of the plant.

By applying a separation of 7.4 m, according to the simulation carried out by the software, during the winter solstice, in 9:15 (am), the solar elevation angle is 15°, the solar azimuth of -52°, the shading factor (linear) (shading factor close) of the whole plant is 0.032, the shading factor (Modular) of the entire plant is of 0.207.

From 9:30 (am), the photovoltaic plant is exposed without shading, in this time then the angle of elevation solar is of 18°, the azimuth solar is of -49°, the shading factor (linear) (close shading factor) of the whole plant is equal to zero.16: 45 (pm), the photovoltaic plant will always be exposed without shading, at this time there, the angle of elevation solar is of 15°, the azimuth solar is of -53°, the shading factor (linear) (close shading factor) of the whole plant is equal to zero.16: 45 (pm), the photovoltaic plant will always be exposed without shading, at this time there, the angle of elevation solar is of 15°, the azimuth solar is of -53°, the shading factor (linear) (close shading factor) of the whole plant is equal to zero.16: 45 (pm), the photovoltaic plant will always be exposed without shading, at this time there, the angle of elevation solar is of 15°, the azimuth solar is of -53°, the shading factor (linear) (close shading factor) of the whole plant is equal to zero.

Sizing of the grouping boxes: this project will be equipped with photovoltaic modules 245Wp, the power of a subfield 1MW is 1002.5kWp. it there has 22 modules for a chain and 186 channels in total is 4092 modules. Each sub-field is equipped with 02 inverters, each general box equipped in one of these two inverters groups together 93 chains of modules, for this purpose, 12 boxes from junction to 08 entries are necessary. The boxes of junction should have the function of supervision of modules to ensure their operation.

System Losses: the design of efficient photovoltaic system requires taking into account of many factors having an impact directly on the ratio of performance of the system. The main sources of energy loss from a ground-mounted solar power plant are as follows:

- Partial shading of the modules.
- The nominal power dispersion.
- Losses by ohmic drop.
- Temperature losses
- Losses by fouling of the modules.
- UPS losses.
- Losses due to the efficiency of other equipment making up the plant (transformer, etc.).
- Losses due to the electrical consumption of auxiliaries.

Deviation of the actual performance of the modules: A power variation limited to 0~5W is required in the contractual files for photovoltaic modules. In the calculations, the deviation of the effective performance of the modules taken into account for this project is 1%, or the positive derivation $245 \times 1\% = 2.45$ w is taken into account.

Ohmic losses in direct current cables: the losses ohmic in the cables to current ongoing understand
that between the modules photovoltaic and the boxes of junction, one between the junction boxes and parallel boxes, the one between the parallel plates and the box general, as between the general box and the inverters. In accordance with the Client's Requirements, the dimensioning of the section of the direct current cable has been made, the cables between the photovoltaic modules adopt copper core conductors with a section of 4 mm\(^2\), the wires between the junction boxes and the boxes adopt parallel conductors of a section of 70 mm\(^2\), the cables between the parallel plates and the box general, as between the general box and the inverters are 240 mm\(^2\) conductors.

The losses ohmic in the cables to current continuously calculated are of 1.9%.

IAM loss: the incidence effect (the term designated is IAM, for "Incidence Angle Modifier", either "the modified angle of incidence" or) corresponds to the decrease in the illumination actually received by the surface of the photovoltaic panels, for example compared to the illumination at normal incidence, due to reflections increasing with the angle of incidence.

In practice, it is often requested using a parameterization called "ASHRAE" (as it has become a standard in this American standard), according to a single parameter \( b \): \( \text{FIAM} = 1 - b \times (1/cosi - 1) \), \( i \) is the angle of incidence on the panels. We take \( b = 0.05 \) in this calculation note. According to the calculations made by the software, the overall IAM factor is 2.7%.

LID loss: LID (Light Induced Degradation, or "degradation induced by the Light") is a performance loss occurring in the early hours of exposure to the sun, with crystalline modules. In particular, it can influence the actual performance compared to final factory flash test data provided by certain manufacturers of photovoltaic modules. We take the LID loss at 1% in this note.

Loss by fouling: the fouling of the modules is a very important parameter when evaluating the energy losses of a solar power plant. The presence of dirt or of sand on the modules will considerably bring down the electrical output of the plant. The losses by fouling are relatively difficult to assess. A loss of 2% has been taken into account for this project.

Ohmic losses in the power cables AC: the length of the AC cable between the inverter and the transformer is of the order of 10 meters, the cable will in the position 30 kV a manner as a loop ring after elevation of voltage by the transformer. The length of the ring circuit is around 710 m. In accordance with the Owner's Requirements, the minimum section of the cable between the inverter and the transformer is 240 mm\(^2\). Under STC conditions, the voltage drop is 6.4 V, the transformer loss is considered 0.1%; the resistance or inductance loss is provisionally estimated at 1%.

Loss through the auxiliary consumption of the power plant: Auxiliary consumption is supplied by the energy produced by the photovoltaic plant itself. Taking into account the electricity consumption of various pumps, air conditioners, MV cells and inverters, the power consumed is of the order of 46 kW. See the Annex - Estimated power balance below.

Loss by temperature: the thermal behavior of the field-which strongly influences the electrical performance-is determined by an energy balance between the ambient temperature and the heating of the cell due to incident irradiation: \( U (T_c - T_a) = \alpha \cdot Ginc \cdot (1 - Ef) \) where \( \alpha \) is the absorption coefficient of the solar radiation, and \( Ef \) is the efficiency photovoltaic (related to the region of the module), to know the energy withdrawn from the module. The usual value of the absorption coefficient \( \alpha \) is 0.9. The central photovoltaic is located in the Sahara, the temperature average annual is very high, causing the loss important by temperature. The calculations performed by the software indicate that the losses overall by temperatures are of the order of 8.6%.

4. Calculation Results

|        | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|
| Energy | 398.7 | 413.2 | 500.0 | 494.2 | 481.7 | 461.3 | 474.2 | 478.8 | 457.5 | 431.0 | 375.7 | 357.3 |

The rate of return will not be less than 91.2% after 10 years of service and will not be less than 80.7%
after 25 years of service. Annual Electricity Production (MWh) for 25 years of service period is presented in the below table, the average annual Electricity Production (MWh) of this central SPP is 4,790.724 MWh.

Table 3. Overall Electricity Production (MWH) for 25 years

| Year | Ep (MWH) | Year | Ep (MWH) | Year | Ep (MWH) | Year | Ep (MWH) |
|------|----------|------|----------|------|----------|------|----------|
| 1    | 5,323.7  | 6    | 5,084.1  | 11   | 4,858.3  | 16   | 4,654.3  |
| 2    | 5,274.9  | 7    | 5,037.4  | 12   | 4,816.8  | 17   | 4,614.6  |
| 3    | 5,226.5  | 8    | 4,991.3  | 13   | 4,775.7  | 18   | 4,575.2  |
| 4    | 5,178.6  | 9    | 4,945.5  | 14   | 4,734.9  | 19   | 4,536.1  |
| 5    | 5,131.1  | 10   | 4,900.1  | 15   | 4,694.4  | 20   | 4,497.4  |
|      |          |      |          |      |          |      |          |
|      |          |      |          |      |          |      |          |
|      |          |      |          |      |          |      |          |
|      |          |      |          |      |          |      |          |
|      |          |      |          |      |          |      |          |
|      |          |      |          |      |          |      |          |
|      |          |      |          |      |          |      |          |
|      |          |      |          |      |          |      |          |
|      |          |      |          |      |          |      |          |
|      |          |      |          |      |          |      |          |
|      |          |      |          |      |          |      |          |
|      |          |      |          |      |          |      |          |
|      |          |      |          |      |          |      |          |
| Annual productivity for 25 years : 32,768.5MWh

The PR average annual is at 78.3%. As shown in the below Chart 2. Performance Index.

5. Conclusion
Based on the results and discussions presented above, the conclusions are obtained as below:

1. It is shown that all the technical requirements in EPC ER have been verified and deemed to be applicable.
2. The electrical production of KAE 3MWp SPP is reasonable and deemed to be achievable.
3. The PR rates for the subject KAE 3MWp SPP is within reasonable ranges and deemed to be technically feasible and economically reasonable.

References
[1] Support vector machine based prediction of photovoltaic module and power station parameters,[J].International Journal of Green Energy, 2020:219-232
[2] Trends in performance factors of large photovoltaic solar plants,[J].Journal of Energy Storage, 2020
[3] Performance analysis of a 10 MWp utility scale grid-connected canal-top photovoltaic power plant under Indian climatic conditions,[J]. Energy, 2020
[4] A comprehensive review on dynamic equivalent modeling of large photovoltaic power plants,[J]. Solar Energy,2020
[5] Performance analysis of a grid-connected photovoltaic plant in eastern Turkey,[J]. Sustainable Energy Technologies and Assessments,2020

5
[6] Study on design optimization of 233MW photovoltaic power station in Algeria, [J]. Yangtze River, 2019(s1): 144-146(in Chinese).

[7] QIAO LILI, Electrical design and analysis of large scale photovoltaic power station,[J]. Heilongjiang Science, 2020, 14(8):144-145(in Chinese).

[8] CHEN JUNXIAN, Common calculation in design of photovoltaic power station [J]. Hongshui River, 2019,6(s1):36-39(in Chinese).

[9] YANG LIULIU, WANGFEI, REN LINTAO, Optimization design and Research on module inclination angle of grid connected photovoltaic power station [J]. Acta Energiae Solaris Sinica,2018(12):3377-3383(in Chinese).

[10] Zhao Xia, Yu Jinhui, Li Han, Zhai Yunfei, Niu Lifang, Liang Fang, Wang Jing, [J]. Calculation and optimization of module series number in photovoltaic power plant design, 2019,6(2):44-47(in Chinese).