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Modeling the relative power reduction factor of a PV generator installed on different piers

Abstract - The factors causing power loss in a generator are numerous; this manuscript is dedicated to modeling and simulating the influence of trellises (-reinforced concrete, -iron, -steel, -aluminum, -sand, -earth, -gravel, water, -seckho, -baked brick, -air, and -straw) on the power of a PV Generator (PVG). The objective is to observe the losses due to the heating of the Back Surface Field (BSF) of the PVG caused by the different types of trellises. The test is carried out over a period of 5, 10, 15, 20, and 25 years at different installation sites.The results from the MATLAB/script simulation showed that the supports on which the PV system is installed over 5 years reduce the power by: 26.36%, 25.32%, 26.97%, 22.14%, 22.62%, 23.90%, 27.60%, 24.64%, 23.80%, 27.51%, and 21.42% for the different piers. Our PV system experienced an average power loss factor of: 20.90% (5 years), 20.01% (10 years), 23.01% (15 years), 22.25% (20 years), and 21.53% (25 years). It appears that a favorable site for installing a PV system is either to suspend it at a certain height (pier-air) or to install it on water (pier-water).

Keywords: Modeling-Power Loss-Pier-PV System.

Introduction

Experiments have shown that after prolonged exposure to natural climatic conditions, thermal stresses and a deterioration in the electrical performance of photovoltaic modules are observed [[1], [2], [3], [4]]. Therefore, a thorough analysis of the causes of the reduction in maximum power and the aging of PV systems is necessary. Such an analysis inevitably involves studying the degradation of the I-V curve due to the effects of the mounting structure or site-specific factors (surface: concrete, sheet metal, metal, wood, planks, seckho, sand, water, vegetation, etc.) on PV modules installed in a harsh environment.Let us recall that the metallic contacts on the emitter and the substrate serve to collect the photogenerated carrier current; the contacts must be ohmic [5]. The rear surface (full metallization) of the solar cell is characterized by a very high surface recombination velocity. The back surface electric field (Back Surface Field, BSF) involves creating a potential barrier (for example, a p+-p or n+-n junction) on the rear side to ensure passivation.The potential barrier induced by the difference in doping levels between the base and the BSF tends to confine minority carriers within the base. As a result, they are kept 28 away from the rear surface. Therefore, the absence of an electric field at the rear surface near the 29 ohmic contact causes the minority carriers to be drawn into the space charge region, leading to 30 poor collection. This results in a deterioration of photocurrent, open-circuit voltage, and 31 photovoltaic conversion efficiency [6]. This article aims to observe the modeling of power 32 evolution of a PV system installed on different trestles. To carry out this work, we structured it 33

2 into three sections: the first section (1) presents and describes the phenomenon of trestles on the 34 solar cell; the second section (2) covers the mathematical and material formalisms; the last 35 section (3) presents the results and discussion [7-8]. 36 1. Degradation of the PV module 37 Published data on photovoltaic (PV) degradation rates have been aggregated and re-examined. 38 The topic has garnered increased interest in recent years, leading to over 11,000 degradation 39 rates reported across nearly 200 studies conducted in 40 different countries. (Dirk Jordan, Sarah 40 Kurtz, Kaitlyn VanSant, Jeff Newmiller). 41 1.1. Factors of cell degradation 42 This section describes the various rates resulting from the degradation of PV in a harsh 43 environment. The degradation of PV modules is related to the decline in the electrical 44 performance parameters of the modules, such as the short-circuit current, open-circuit voltage, 45 and fill factor. These electrical performance parameters depend on the solar cell parameters, such 46 as the reverse saturation current, the ideality factor, and parasitic resistance (series resistance and 47 shunt resistance), which are the basis for losses in PV modules [[9] - [14]].According to Un. 48 Bouaichi, et al. [15], high temperatures and humidity discolor the transparent ethylene-vinyl 49 acetate (EVA) encapsulation sheet of photovoltaic modules and prevent incident photons from 50 reaching the solar cells. This degrades the short-circuit current and the output power of PV 51 modules [[8] - [28]].Another key factor that accelerates the degradation of photovoltaic modules 52 is the accumulation of dust on the modules. The accumulation of dust on photovoltaic modules 53 largely depends on the

properties of the dust such as weight, shape, size, and chemical 54 properties, as well as environmental conditions such as weather, environmental characteristics, 55 and site-specific factors. In Iraq, M.A. Hadnan et al. 2024 [29] stated the impact of soiling losses 56 on energy yield, revealing potential losses of up to 70%. 57 Furthermore, despite evidence suggesting variations in degradation rates depending on climatic 58 conditions ([3] - [30]), photovoltaic panel manufacturers have been reluctant to implement 59 performance degradation warranties based on the racking. This divergence highlights the need 60 for comprehensive global assessments of the reduction rates of photovoltaic modules in order to 61 provide manufacturers with concrete evidence of the differentiation of degradation rates related 62 to different types of racking. 63 1.2. Mathematical formalism for evaluating PV degradation 64

3 1.2.1. Photovoltaic Generator (PVG) 65 The specific site factor (Pinst) allows for the observation of losses in a PV generator due to the 66 effects of the structure. It is the factor that multiplies the photocurrent and affects the incident 67 flux (generation-recombination rate) and the carrier diffusion length rates (Ln, Lp) [[3], 68 [19]].Losses at the surface of the solar cell are modeled by surface recombination with a rate that 69 characterizes the quality of the surfaces. The base of the solar cell consists of two regions: the 70 actual base and a heavily doped area near the rear ohmic contact. Such a structure leads to two 71 consequences: the creation of a small additional energy barrier and the confinement of minority 72 carriers in the base.In this way, the charge carriers generated at the back of the base near the 73 ohmic contact, which are normally lost in simple cells, are recovered. The loss of minority 74 carriers at the rear surface of the solar cell is quantified by the recombination current at the 75 surface of the rear ohmic contact; given by equation [[1] - [2]]: 76 $I = IP\square ref - Ki\ .\ T - T\ ref\ \ .\ \varepsilon fss\ .G\ GRef$ -I0. $exp\ \ V{+}RS\ .I\ m\ .V\ t$ − 1 − $V{+}RS\ .I\ RP$. 1 + a 1 − $V{+}RS\ .I\ {-}n\ Vb$ (1) 77 $T = NOCT{-}20$ 0.8 . $G + T\ a$ (2) 78 T: is the temperature under normal NOCT conditions 79 This equation describes the current flowing through the solar cell by applying Kirchhoff's law. 80 Note: At the MPPT (Maximum

Power Point Tracking) point and under NOCT conditions, we are: $G = 1000\ W/m^2$, $T = 25°C$, $AM = 1.5$, $I_m \approx 0.8.\ I_{CC}$ et $V_m \approx 0.8 V_{CO}$ (4) Temporary degradation rate The temporary degradation rate due to the specific site factor is given by: $\tau_{fss}\ \% = 1 - \frac{X_{mes}}{X_m} . 100$ et $\tau_{Jour} = \frac{\tau_{fss}\ \%}{t_{expo}}$ (5) 1.2.2. GPV Power Losses In this section, we explain the modeling process. We took into account: The installation duration, the technology, the power characteristics, the specific site, and the orientation angle of the cell. We varied the site specificity (reinforced concrete, sheet metal, tile, back sheet, earth, sand, water, straw, aluminum, soil, diatomaceous earth, natron, clay, plastic, glass, vacuum) for the same PV system, then we proceeded to measure the values using a digital multimeter and a pyrometer.

4 2. Materials and Methods 2.1. Module & Simulation Parameters STC module power [W]: P_STC = 300 Wc; Temperature coefficient (°C): temp_coeff = -0.004; => -0.4%/°C => -0.004 /°C Nominal Operating Cell Temperature [°C]: NOCT = 45; Annual intrinsic degradation (0.5%/year): intrinsic_deg_rate = 0.005; Simulation duration [years]: years = 5, 10, 15, 20, and 25 years; Time step in hours: dt = 1; t_hours = 0:dt:(years*365*24 - 1); t_years = t_hours / (365*24); Irradiance/day: Irradiance = hourly profile sine + seasonal variation (6) With: Gmax = 1000 W/m2 peak Daily factor: day_factor = 1 + 0.2sin(2π ∗ t_years); (7) Seasonal variation: Seasonal variation +/−20 hour_of_day = mod(t_hours, 24); (8) G = Gmax . max(0, sin(pi ∗ hour_of_day / 12)) .∗ day_factor (9) Ambient temperature: Ambient temperature = seasonal variation + daily variation Average temperature: Tamb_mean = 20 °C Seasonal amplitude: Tamb_amp_season = 8; Daily amplitude: Tamb_(amp_diurnal) = 5; Tamb = Tamb_mean + Tamb_amp_season ∗ sin(2π ∗ t_years − 0.5) . . . + Tamb_amp_diurnal ∗ sin(2π∗hour_of_day 24);(10) Table 1. Table of substrates (assumptions) fields name Name deltaT_eff effect of the substrate on module temperature at 1000 W/m² [°C]

soiling_rate deposit accumulation rate (1/year) max_soiling maximum relative loss due to soiling (fraction) corrosion_rate corrosive effect in additional annual relative loss

5 $nSubs = length(substrates)$; Calculations for each substrate Instantaneous power [W] $P\_time = zeros(nSubs, length(t\_hours))$; Power relative to STC $relPower = zeros(nSubs, length(t\_hours))$;   for k = k = 1: nSubs s = substrates(k); (11) Approximate cell temperature = Tamb + (NOCT − 20)/800 ⋆ G + substrate effect pro rata G/1000(12) Tcell = Tamb + (NOCT − 20)/800 .⋆ G + s. deltaT_eff .⋆ (G/1000); (13) Cumulative soiling over time: soiling_frac(t) = max_soiling ⋆ 1 − e −soilin grate ⋆ tyears ; (14) soiling_frac = s. max_soiling .⋆ 1 − e −soilin grate ⋆ tyears ;(15) Annual multiplicative degradation (intrinsic + corrosion), applied over time: $factor = e(t\_years \star ln$ (1 − $total\ \_rate$)) (16) $totalrate = intrinsicde\ grate + s \star corrosion\_rate$; (17)

To avoid a negative base if total_rate>1, we take an approximate negative exponent: deg$factor = e - tota\ lrate$.⋆ $tyears$; (18)

$e(-rate \star t) \approx et\star$ln 1−$rate$, $pourlesp$é$titsrates$ (19) Instant power:

$P = P\_STC \star (G$ 1000) ⋆ (1 + $temp\_coeff \star (Tcell$ − 25)) ⋆ (1 − $soiling\_frac$) ⋆ deg_factor

(20)

6 P_inst = P_STC .⋆ (G 1000)(1 + temp_coeff .⋆ (Tcell − 25)) .⋆ (1 − soiling_frac) .⋆ deg_factor;

(21) Clamp negatives $P\_inst(P\_inst < 0) =$ 0; (22) $P\_time(k, :)$ = P_inst;(23) P_STC fraction relPower(k, :) = P_inst ./ P_STC;(24) 2.2.

Equipment   150 The different platforms for installing a photovoltaic system. 151 152

Figure 1. Different types of photovoltaic installation racks 153 Matlab 2025b 154 155

Figure 2. Workstation 156 Computer: Surface Go I5 10th Generation N2B2UOM 157 3.. Results and Discussion 158

7 This section presents the results of our simulation 159 3.1. Simulation of the relative power of the GPV according to different piers 160 The figure below shows that the power is affected by the site characteristics on which a PV 161 system is installed and by its lifespan. 162 163 Figure 3. Evolution of relative power according to the type of piers 164 Figure 3 describes the influence of different piers on the relative power (PSTC). We observe that 165 with iron, aluminum, and gravel piers, the losses are more pronounced than at other sites. This 166 reduction ultimately leads to the degradation of the photovoltaic panel, which in turn causes the 167 disintegration of the associated static converters. This demonstrates that a very specific site must 168 be chosen to install PV systems; however, in sub-Saharan Africa, and especially in Chad, solar 169 panels are generally installed directly on the ground or on metal roofs. Also, it should be noted 170 that over time, the voltage drops due to the effects of piers increase, as highlighted in the figure 171 above. 172

8   173 Figure 4. Zoom on the influence of different jetties 174 In this Figure 4, we observe that the PV system loses more of its performance when installed on 175 sand, straw, and soil. This can be explained by the fact that the Sahelian climate, coupled with 176 the thermoelectric properties of these sites (sand, straw, and soil), affects the performance of the 177 PV system. 178 179 Figure 5. Acceptable range of pier areas 180 Figure 5 shows the range of acceptable piers for the installation of a photovoltaic generator 181 without significant power loss. To outline these areas, we drew a line using the geometric 182 regression law y = f(x) based on the simulated data. 183

9 Thus, this curve serves as a boundary: above it, conditions are considered favorable for optimal 184 efficiency. Conversely, sites located below the line y = f(x) show insufficient performance and 185 are not recommended. The position of a point relative to the line takes into account factors such 186 as the angle of incidence, reflection, and environmental absorption. We have identified several 187 materials and surfaces (piers) that enhance capture and minimize losses. 188 Reinforced concrete, for example, provides a stable and reflective surface that limits the effects 189 of local shading. Aluminum offers good reflectivity and durability, supporting consistent 190 performance. Fired brick combines thermal inertia with a texture suitable for long-lasting 191 installation. Water, when present in a calm and reflective form, can increase the received 192 irradiation through reflection. Air, understood here as open areas without obstacles, reduces 193 losses related to shading and diffusion. Consequently, we recommend installing PV generators 194 on these supports or in these environments when conditions allow. For sites below y = f(x), 195 corrective measures (elevation, change of orientation, or surface treatment) are necessary before 196 installation. 197 198 Figure 6. Range of the favorable zone over 25 years 199 In this figure 6, we observe that even over a period of 25 years, sites made of reinforced 200 concrete, aluminum, air, and water have remained favorable for solar installations. 201

10 202 Figure 7. Comparison of power loss factors at different sites over periods of 5, 10, 15, 20, 203 and 25 years. 204 Figure 7 compares the rate of reduction in GPV power across different types of piers over a 205 period ranging from 5 to 25 years in 5-year increments. It appears that: in the case of reinforced 206 concrete during the first period of 5 to 10 years, GPV is not significantly affected by thermo207 electric factors due to the local climate. In the case of air, water, and aluminum, these materials 208 constitute favorable piers for optimizing GPV performance. 209 4.. Conclusion 210 In this article, a simulation is conducted to observe the influence of racks on the power of a 211 300Wp PV system. Among the various installation sites, we found that platforms made of 212

concrete, aluminum, air, and water remain favorable supports for BSF protection and contribute 213 to optimizing production, whereas other sites significantly affect the efficiency of the PV system. 214 This result explains that the installation of a PV system in households should no longer be done 215 at random, as one of the sources of voltage drops and the degradation of photovoltaic converters 216 is due to the racks on which the panels are mounted. 217 5.. References 218 0 5 10 15 20 25 30 Comparison of power loss factors of different sites over periods of : 5, 10, 15, 20, and 25 years 5 years 10 years 15 years 20 years 25 years

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