RAD FOTONAPONSKOG PARKA NA OTOKU KRETI
A PHOTOVOLTAIC PARK'S PERFORMANCE ON THE ISLAND OF CRETE

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Povoljni klimatski uvjeti otoka Krete i novije zakonodavstvo o obnovljivim izvorima energije pružaju znatan poticaj za uvođenje fotonaponskih elektrana. U ovom prikazu predstavljen je fotonaponski park (FN Park) C. Rokas u Sitiji, Kreta i ocijenjen njegov rad. Taj fotonaponski park, koji je u pogonu od 2002. godine, ima vršnu snagu od 170 kWp. Park se na prikladan način kontrolira godinu dana interno, a izračunavaju se stupanj djelovanja (eng. *performance ratio*) i razni gubici snage (temperaturni, onečišćenje, unutarnji gubici u mreži, energetska elektronika, raspoloživost i međuspoj mreže). Tijekom 2007. park je u mrežu isporučio 230 MWh, i to u rasponu od 335 do 870 kWh dnevno. Proizvodnja na instaliranoj snazi (YF) kretala se od 2 h/d do 5 h/d, a faktor iskorištenja od 58 % do 73 %, što je rezultiralo godišnjim faktorom iskorištenja od 67,36 %.

The favorable climate conditions of the island of Crete and the recent legislation for the utilization of renewable energy sources, provide a substantial incentive for the installation of photovoltaic power plants. In this paper, the grid-connected photovoltaic park (PV park) of C. Rokas SA in Sitia, Crete is presented and its performance is evaluated. The photovoltaic park has a peak power of 170 kWp, and has been in operation since 2002. The park is suitably monitored for a one year internal and the performance ratio and the various power losses (temperature, soiling, internal network, power electronics, grid availability & interconnection) are calculated. The PV Park supplied 230 MWh to the grid during 2007, ranging from 335 kWh to 870 kWh per day. The final yield (YF) ranged from 2 h/d to 5 h/d and the performance ratio (PR) ranged from 58 % to 73 %, giving an annual PR of 67,36 %.

Ključne riječi : faktor angažirane snage, fotonaponski park, gubici snage, ukupna proizvodnja, proizvodnja energije, referentna proizvodnja, faktor iskorištenja, vršna snaga

Key words : capacity factor, energy output, final yield, peak power, performance ratio, photovoltaic park, power losses, reference yield

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1 UVOD

Grčko tržište solarne energije naglo raste i privlači ogroman interes investitora zbog nedavno donesenog zakona o sustavu zajamčenih cijena [1] koji jamči cijenu između 0,4 EUR/kWh i 0,5 EUR/kWh za 20-godišnje razdoblje te dopunsku investicijsku subvenciju od 20 % do 40 %. Prema tome, vrijeme povrata investicije u Grčkoj kao zemlji s vrlo visokom insolacijom možda je najniže u cijeloj Europi. Da bi se izvukla korist od takva rasta, analiza stvarnog učinka najvećeg instaliranog fotonaponskog parka (FN park) u Grčkoj, posebice na otoku Kreti s najvišim insolacijskim vrijednostima u Europi, od velike je važnosti za definiranje investicijskih očekivanja u smislu učinkovitosti sustava, a time i gospodarske koristi. Nadalje, ocjena radnog učinka u odnosu na stvarne podatke omogućava otkrivanje pogonskih problema, olakšava usporedbu izvedbeno različitih sustava, te utvrđuje interakciju FN parka s lokalnom mrežom, što je od velikog značaja u nekom velikom autonomnom elektroenergetskom sustavu kao što je kretski [2] i [3].

Pilot projekt FN park C. Rokas lociran je u Ksirolimniju, Sitia na otoku Kreti. U ovom članku analiziran je rad mreže na satnoj, dnevnoj i mjesečnoj osnovi za 2007. godinu. Izvedeni parametri uključuju referentnu proizvodnost, proizvodnost grupe panela, područje krajnjeg prinosa, gubitke pretvorbe primarnog oblika energije, gubitke sustava i stupanj djelovanja.

2 FOTONAPONSKI PARK (FN PARK)

FN park C. Rokas najveći je grčki FN park u pogonu sa instaliranim kapacitetom 170 kWp koji je spojen na 20 kV dalekovod. FN park pokriva ukupno područje od 3 784 m^2 i aktivno područje od 1 142,4 m^2. Fotonaponska elektrana sastoji se od fotonaponskih (FN) modula 1428 MSX 120 Solarex (engl. BP Solar) od polikristalnog silicija. FN moduli su raspoređeni u 120 paralelnih nizova (engl. *strings*), sa po 12 modula u svakom, spojenih na 60 invertera Sunny Boy SB 2500 montiranih na noseću konstrukciju, uz što se nalaze priključne kutije, instrumentacija za mjerenje zračenja i temperature, te sustav za zapisivanje podataka.

Inverteri su priključeni na elektroenergetsku mrežu preko transformatora 0,4/20 kV i brojila električne energije. FN sustav montiran je na noseću konstrukciju od nehrđajućeg čelika okrenutu prema jugu pod kutom od 30°. Taj kut nagiba izabran je da bi se maksimalizirala godišnja proizvodnja energije. Slika 1 prikazuje FN park, a slika 2 prikazuje jednopolnu shemu priključka FN parka na elektroenergetski sustav.

1 INTRODUCTION

The Greek photovoltaic market is rapidly growing, attracting an enormous investment interest due to the recently launched feed-in tariff (RES law) [1] guarantying a price between 0,4 EUR/kWh and 0,5 EUR/kWh for a 20-year period and a supplementary investment subsidy at 20 % to 40 %. Therefore, the payback time of an investment in Greece with very high insolation may be the lowest in whole Europe. To benefit from this growth, the actual performance analysis of the largest installed photovoltaic Park (PV park) in Greece, and especially on the island of Crete with one of the highest insolation values across Europe, is of great importance in order to set the investor's expectations for system performance and the associated economic return. Furthermore, the performance evaluation with real data can allow the detection of operational problems, facilitate the comparison of systems that may differ with respect to design, and evaluate the interaction of the Park with the local grid, which is of high significance in a large autonomous electric system, such the Cretan one [2] and [3].

The pilot PV Park C. Rokas is located in Xirolimni, Sitia, Crete. In this paper, the performance of the grid connected for the year 2007 has been analysed on hourly, daily and monthly bases. The derived parameters include reference yield, array yield, final yield array, capture losses, system losses, and performance ratio.

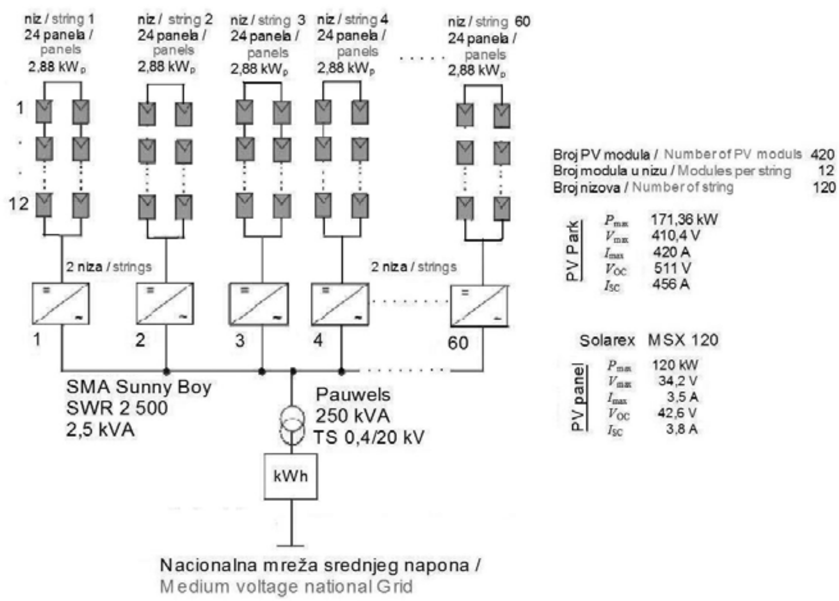
2 PHOTOVOLTAIC PARK

The PV Park is the largest operating PV Park in Greece with an installed capacity of 170 kWp grid connected to a 20 kV TEP transmission line and covering a total surface area of 3 784 m^2, and an active area of 1 142,4 m^2. The park is comprised of a 1 428 MSX 120 Solarex (BP Solar) polycrystalline silicon PV modules. The PV modules are arranged in 120 parallel strings, with 12 modules in each, and connected to sixty Sunny Boy SB 2500 inverters installed on the supporting structure, plus connection boxes, irradiance and temperature measurement instrumentation, and data logging system.

The inverters are linked to the national grid via a 0,4/20 kV transformer and an electrical energy meter. The PV system is mounted on a stainless steel support structure facing south and tilted at 30°. Such a tilt angle was chosen to maximise yearly energy production. Figure 1 shows the PV park, and Figure 2 shows a schematic block circuit diagram of the system's electrical connection.

Slika 1 — Pogled na FN park C. Rokas SA — FN moduli nagnuti su 30°, orijentirani prema jugu (u pozadini susjedna vjetroelektrana)

Figure 1 — View of the C. Rokas SA Photovoltaic Park, the FN modules are tilted at 30° and oriented south (the adjacent wind park in the background)



Slika 2 — Shematski blok dijagram FN sustava

Figure 2 — Schematic block circuit diagram of the FN system

3 ANALIZA SUSTAVA

FN sustav parka detaljno je analiziran kako bi se procijenila učinkovitost sustava pri radu paraleno s lokalnom elektroenergetskom mrežom. Za ocjenu učinkovitosti FN parka proračunati su ukupna proizvodnost (Y_F), referentna proizvodnost (Y_R), stupanj djelovanja - performance ratio (PR) i faktor opterećenja (CF) prema definiciji standarda IEC 61 724 [4].

Ukupna proizvodnost (Y_F) definira se kao godišnja,

3 SYSTEM ANALYSIS

The PV Park system has been fully monitored to assess its performance with the local power grid. To evaluate the PV Park performance, the final yield (Y_F), the reference yield (Y_R), the performance ratio (PR) and the capacity factor (CF) were calculated as defined by the IEC Standard 61 724 [4].

The final yield (Y_F) is defined as the annual, monthly or daily net AC (alternating current) energy output (E) of the system divided by the peak power (P_r) of mjesečna ili dnevna neto proizvodnja električne energije na srednjenaponskoj strani priključnog transformatora (E) podijeljena s vršnom snagom (P_r) instaliranog fotonaponskog sustava u standardnim ispitnim uvjetima (SIU) sunčeva zračenja od 1 000 W/m^2 i temperature ćelija od 25 °C:

the installed PV array at Standard Test Conditions (STC) of 1 000 W/m^2 solar irradiance and 25 °C cell temperature:

$$Y_F = \frac{E}{P_r} . \tag{1}$$

Referentna proizvodnost (Y_R) je ukupna solarna insolacija na plohi H_t (kWh/m^2) podijeljena s referentnim zračenjem za grupu FN panela (kW/m^2); dakle, referentna proizvodnost je broj vršnih sunčanih sati:

The reference yield (Y_R) is the total in-plane solar insolation H_t (kWh/m^2) divided by the array reference irradiance (kW/m^2); therefore, the reference yield is the number of peak sun-hours:

$$Y_R = \frac{H_t}{1} \frac{\left[\mathrm{kWh/m^2}\right]}{\left[\mathrm{kW/m^2}\right]} = \frac{H_t}{1} \left[\mathrm{h}\right] . \tag{2}$$

Stupanj djelovanja (PR) je ukupna proizvodnost podijeljena s referentnom proizvodnosti; on predstavlja ukupne gubitke u sustavu s pretvaranjem istosmjerne struje (DC) u izmjeničnu (AC). Tipični gubici FN parka uključuju gubitke zbog degradacije panela (η_{deg}), temperature (η_{tem}), onečišćenja (η_{soil}), unutarnje mreže (η_{net}), invertera (η_{inv}), transformatora (η_{tr}) i raspoloživosti sustava te priključenja na mrežu (η_{ppc}). Stoga se stupanj djelovanja (PR) može izraziti kao:

The performance ratio is the final yield divided by the reference yield; it represents the total losses in the system when converting from nameplate DC (direct current) rating to AC output. The typical losses of a PV park include losses due to panel degradation (η_{deg}), temperature (η_{tem}), soiling (η_{soil}), internal network (η_{net}), inverter (η_{inv}), transformer (η_{tr}) and system availability and grid connection network (η_{ppc}). Therefore, the PR can be expressed as:

$$PR = \frac{Y_F}{Y_R} = \eta_{deg} \cdot \eta_{tem} \cdot \eta_{soil} \cdot \eta_{net} \cdot \eta_{inv} \cdot \eta_{tr} \cdot \eta_{ppc} . \tag{3}$$

Proizvodnost grupe panela (Y_A) definira se kao godišnja ili dnevna proizvodnja energije FN područja podijeljena s vršnom snagom (P_R) instalirane grupe FN panela; gubici sustava (L_S) uključuju gubitke konverzije invertera i transformatora, a gubici prihvata energije unutar grupe panela (L_C) uzrokovani su gubicima unutar FN modula u toj grupi:

The array yield (Y_A) is defined as the annual or daily energy output of the PV array divided by peak power of the installed PV, the system losses (L_S) are gained from inverter and transformer conversion losses, whereas the array capture losses (L_C) are due to PV array losses:

$$Y_A = \frac{E_A}{P_R} , \tag{4}$$

$$L_C = Y_R - Y_F , \tag{5}$$

$$L_S = Y_A - Y_F . \tag{6}$$

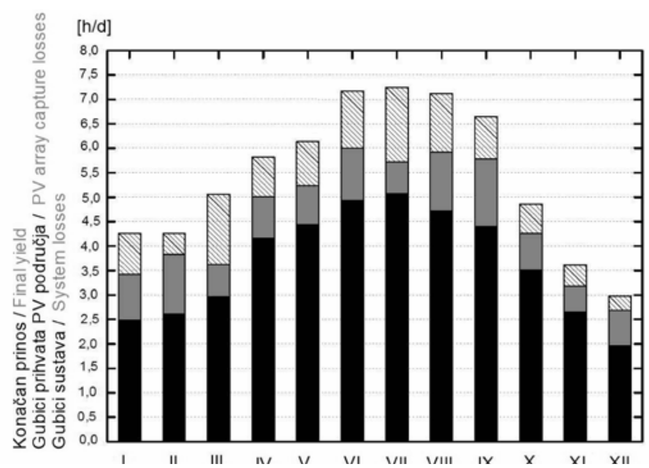
Konačno, faktor opterećenja (CF) definira se kao omjer stvarne godišnje proizvodnje električne energije i električne energije koju bi FN park proizveo kada bi radio snagom punog kapaciteta (P_r) neprestano cijele godine:

Finally, the capacity factor (CF) is defined as the ratio of the actual annual energy output and the amount of energy the PV Park would generate if operating at full rated power (P_r) for 24 hours per day for a year:

$$CF = \frac{Y_F}{8\ 760} = \frac{E}{P_{r*}8\ 760} = \frac{H_t}{P_{r*}8\ 760} \ . \qquad (7)$$

Trenutno globalno zračenje u zoni grupe FN modula, temperatura okoline, izlazna DC snaga grupe FN modula i izlazna AC snaga FN parka bili su mjereni svakih 10 minuta i spremani u bazu podataka. Mjesečna proizvodnja električne energije na priključnoj točki mreže također je bila dana od grčke elektroprivrede PPC (odnosno operatora mreže). Potpuni pogonski podaci iz baze podataka za 2007. godinu bili su uprosječeni svakih 10 minuta tijekom tipičnog dana i to za cijeli mjesec. Slika 3 prikazuje ukupnu mjesečnu uprosječenu insolaciju u zoni zajedno s mjesečnom temperaturom okoline uprosječenom kroz sate preko dana.

The incident global irradiance in array plane, the ambient temperature, the DC array output power, and the PV Park AC output power were measured every 10 minutes and stored in the logger system. The monthly AC output energy at the grid connection point was also given by the Greek PPC (grid connection network). Complete operation data from the logger for the year 2007 was averaged for every 10 minutes during a typical day per month. Figure 3 shows the monthly averaged total in-plane insolation together with the monthly ambient temperature averaged over the daytime hours.



Slika 3 — Ukupna mjesečna uprosječena insolacija u zoni i temperatura okoline uprosječena kroz sate preko dana u godini 2007.

Figure 3 — Monthly averaged total in-plane insolation and ambient temperature averaged during the daytime hours over the year 2007

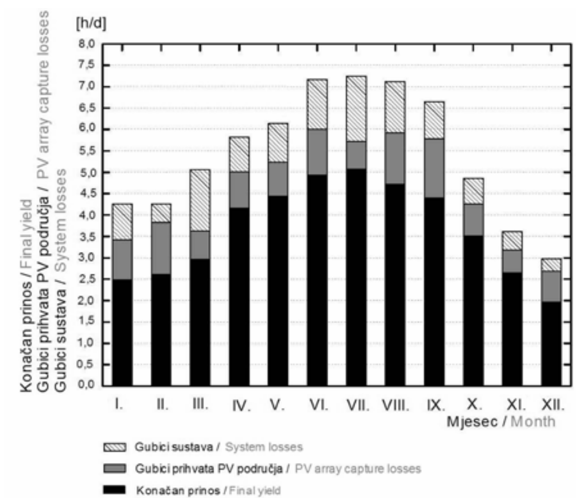
Najviša vrijednost ukupne insolacije u plohi iznosila je u srpnju 225 kWh/m^2, a najniža u prosincu 92 kWh/m^2. Godišnja insolacija iznosila je 1985 kWh/m^2 a srednja temperatura okoline 16,46 °C. U 2007. godini FN park proizveo je 229 MWh, u rasponu od 10,4 MWh (prosinac) do 27 MWh (srpanj) mjesečno. Slika 4 prikazuje mjesečno uprosječeni dnevni konačni prinos, područne gubitke prihvata i gubitke sustava. Mjesečno uprosječena dnevna prozvodnost grupe panela kretala se od 2,25 h/d (prosinac) do 6,6 h/d (srpanj), a ukupna proizvodnost od 1,95 h/d do 5,07 h/d. Prosječna godišnja

The highest value of total in-plane insolation was in July with 225 kWh/m^2, and the lowest in December with 92 kWh/m^2. The annual insolation was 1 985 kWh/m^2 and the mean ambient temperature was 16,46 °C. The PV Park generated 229 MWh in 2007, ranging from 10,4 (December) to 27 MWh (July). Figure 4 shows the monthly averaged daily final yield, array capture losses and system losses. The monthly averaged daily array yield ranged from 2,25 (December) to 6.6 h/d (July), and the final yield from 1,95 h/d to 5,07 h/d. The average annual final yield and reference yield was 1 337 ukupna proizvodnost i referentna proizvodnost iznosili su 1 337 sati odnosno 1 984 sati. Mjesečno uprosječeni dnevni gubici grupe FN modula kretali su se od 0,54 h/d (studeni) do 1,38 h/d (rujan), a gubici sustava od 0,29 h/d (prosinac) do 1,52 h/d (srpanj). Stupanj djelovanja bio je raspoređen u rasponu od 58 % do 73 %, dok je godišnja srednja vrijednost bila 67,36 %.

Ukupna godišnja proizvodnost od 1.337 kWh/kWp za FN park značajno je viša od FN parkova u Njemačkoj [5] i slična je FN parkovima u južnoj Španjolskoj [6], što ilustrira ogromne potencijale ulaganja u otok Kretu. Prosječni godišnji faktor angažirane snage iznosio je 15,26 %.

and 1 984 hours, respectively. The monthly average daily array losses ranged from 0,54 h/d (November) to 1,38 h/d (September), and the system losses from 0,29 h/d (December) to 1,52 h/d (July). The performance ratio was distributed within the range of 58 % to 73 %, and the annual mean value was 67,36 %.

The annual final yield of 1 337 kWh/kWp for the PV Park is significantly higher than PV parks operated in Germany [5] and similar to parks operated in Southern Spain [6], demonstrating the huge potential of an investment in the island of Crete. The average annual capacity factor was 15,26 %.



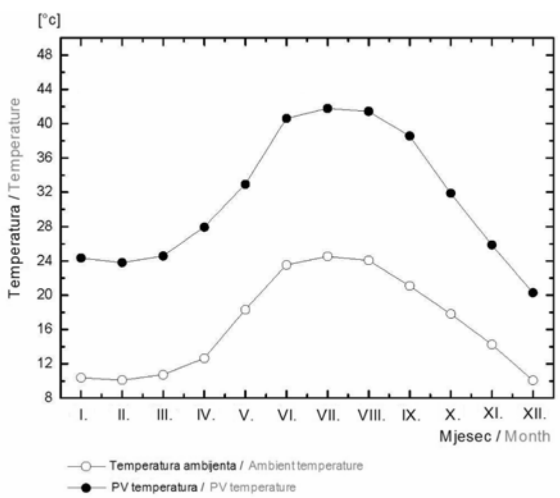
Slika 4 — Mjesečno uprosječeni dnevni konačni prinos, gubici prihvata FN područja i gubici sustava
Figure 4 — Monthly averaged daily final yield, FN array capture losses and system losses

Metodologija koja se koristi za analitički proračun raznih gubitaka FN parka može se opisati kako slijedi: Sučevo zračenje u plohi, temperatura okoline preko dana, DC snaga grupe FN modula i izlazna AC snaga parka uprosječene su u 10-minutnim intervalima tijekom tipičnog dana mjesečno. Nominalna trenutna DC snaga grupe FN modula (10 minutni prosjek) i ukupna godišnja izlazna energija izračunavaju se uporabom podataka o sunčevu zračenju i tehničkih specifikacija korištenih fotonaponskih panela. Zatim se stvarna izlazna snaga grupe FN modula postepeno simulira uračunavanjem različitih gubitaka uslijed; degradacije FN modula, gubitaka uzrokovanih temperaturom i onečišćenjem. Isti se put slijedi za izračun gubitaka međuspoja, invertera i transformatora koreliranjem stvarne proizvodnje grupe FN panela s proizvodnjom energije FN parka na bazi 10-minutnih podataka. Ova metoda pruža realnu procjenu, budući da su razni gubici stavljeni u međusobnu vezu i izravno povezani sa stvarnom trenutnom proizvodnjom energije FN panela i FN parka.

The methodology followed to analytically calculate the various losses of the PV Park can be described as follows: The in-plane solar radiation, the ambient daytime temperature, the array DC power and the park AC output power are averaged with a 10 minutes frequency during a typical day per month. The nominal instantaneous array DC power per 10 minutes and the total array annual output energy are calculated using the solar radiation data and the technical specifications of the photovoltaic panels used. Then, the real array output power is simulated gradually adding various losses of the array; the degradation modulus, the temperature and the soiling losses. The same routine is followed for the calculation of the interconnection, inverter and transformer losses by correlating the real array power output with the PV Park power output with a 10 minutes frequency. This method gives a realistic estimate, since the various losses are interrelated and directly linked with the instantaneous real power output of the PV panels and the PV Park.

Učinkovitost jednog FN panela ovisi o radnoj temperaturi i energijskoj gustoći sunčeva zračenja. Kako se povećava temperatura FN panela, učinkovitost se linearno smanjuje, budući da se vršna snaga FN panela odnosi na SIU uvjete. U različitim temperaturama izlazna snaga FN panela ovisi o razlici temperature panela i SIU temperature (T_C – T_{STC}) te o energijskoj gustoći (G) vjerojatnog sunčeva zračenja. Na slici 5 prikazani su radna temperatura FN modula i temperatura okolne mjerene u satima između izlaska i zalaska Sunca kroz promatrano razdoblje.

The efficiency of a PV panel depends on the operation temperature and the power density of the solar radiation. As the temperature of the PV panels increases, the efficiency decreases linearly, since the peak power of the PV panels refers to STC conditions. In different temperatures, the output power of the PV panels depends on the difference between the panel temperature and the STC temperature (T_C – T_{STC}) and on the power density (G) of the incident solar radiation. The PV module monthly operating temperature and the ambient temperature measured during daylight hours over the monitored period are shown in Figure 5.



Slika 5 — Mjesečno prosječna satna temperatura zraka okoline i temperatura FN modula mjerena u satima od izlaska do zalaska Suncaza 2007.

Figure 5 — Monthly average hourly ambient air and FN module temperature measured during daylight hours for 2007

Ljeti je mjesečno prosječna satna temperatura FN modula varirala između 22 °C i 31 °C, dok se ambijentalna temperatura kretala između 13 °C i 18 °C. Zimi je prosječna satna temperatura FN modula varirala između 10 °C i 12 °C, dok se ambijentalna temperatura kretala između 6 °C i 8 °C.

In summer, the monthly average hourly PV module temperature varied within 22 °C do 31 °C, and the ambient temperature ranged between 13 °C and 18° C. In winter, the average hourly PV module temperature varied from 10 °C to 12 °C, and the ambient temperature ranged between 6 °C and 8 °C.

Koeficijent temperaturnih gubitaka (η_{tem}) može se izračunati kao:

The temperature losses coefficient (η_{tem}) can be calculated as:

$$n_{\text{tem}} = 1 + \beta \left(T_c - 25\right), \quad (8)$$

gdje je:

β – temperaturni faktor FN panela,
T_C – temperatura solarne ćelije,
T_A – temperatura zraka

where;

β – the temperature factor of the PV panel,
T_C – PV cell temperature,
T_A – the air temperature,

Temperatura solarne ćelije (T_C) u korelaciji je s temperaturom zraka (T_A) kako slijedi:

The PV cell temperature (T_C) is correlated with the air temperature (T_A) as follows:

$$T_c = T_a + \frac{G}{G_{NOCT}}(T_{NOCT} - 20) = T_a + \frac{G}{800}(T_{NOCT} - 20) \quad (9)$$

gdje je:

T_{NOCT} – nominalna radna temperatura ćelije i
G – energetska gustoća u određeno vrijeme,
G_{NOCT} – energetska gustoća pri nominalnoj radnoj temperaturi ćelije

Koeficijenti temperaturnih gubitaka izračunati su na temelju 10-minutnih podatala i godišnji gubici zbrojeni su na 7,12 %.

U uvjetima neprekidnog rada FN paneli naposljetku postanu pokriveni tankim slojem prljavštine i prašine, čime se smanjuje količina svjetla što dospijeva do svake ćelije. Količina gubitka snage zbog takva onečišćenja (η_{soil}) ovisi o vrsti prašine (lokalne poljoprivredne djelatnosti), dužini vremena proteklog od zadnje kiše i o programu čišćenja i održavanja. Za konkretni FN park, mjesečni koeficijenti empirički su procijenjeni na temelju studije PVUSA [7] i podataka o padalinama na licu mjesta. Gubici od onečišćenja iznosili su 4 % do 5 % u zimskom i 6 % do 7 % u ljetnom razdoblju, što je rezultiralo godišnjim gubicima od 5,86 %.

Kad su se temperaturni gubici i gubici od onečišćenja dodali nominalnoj proizvodnji energije bez gubitka:

where:

T_{NOCT} – the nominal temperature operational cell temperature and
G – the power density at the particular time,
G_{NOCT} – the power density at the nominal temperature operational cell temperature

The temperature losses coefficients were calculated with a 10 minutes frequency and the annual losses were summed to 7,12 %.

The PV panels under continuous operation eventually become covered with a fine layer of dirt and dust, decreasing the amount of light reaching each cell. The amount of power loss due to soiling (η_{soil}) depends on the type of dust (local agricultural activities), the length of time since the last rainfall and the cleaning maintenance schedule. For the specific PV Park, the monthly coefficients were empirically estimated based on the PVUSA study [7] and the rainfall data of the site. The soiling losses were 4 % to 5 % during the winter and 6 % to 7 % during the summer period, resulting in annual losses at 5,86 %.

By adding the temperature and soiling losses to the nominal array power output without losses:

$$P_{PV} = \frac{P_r \cdot G}{1} \ , \quad (10)$$

primijećeno je neslaganje od 5 % u usporedbi sa stvarnom zabilježenom izlaznom snagom. To se neslaganje može pripisati gubicima od degradacije FN panela (η_{deg}) tijekom starenja, budući da je FN park u punom pogonu od 2002. godine. To se u potpunosti slaže s eksperimentalnim studijama kao i s izjavama i jamstvima proizvođača, time što prve energetske deklaracije navode 5 % uz maksimalni vijek trajanja od 20 % [8].

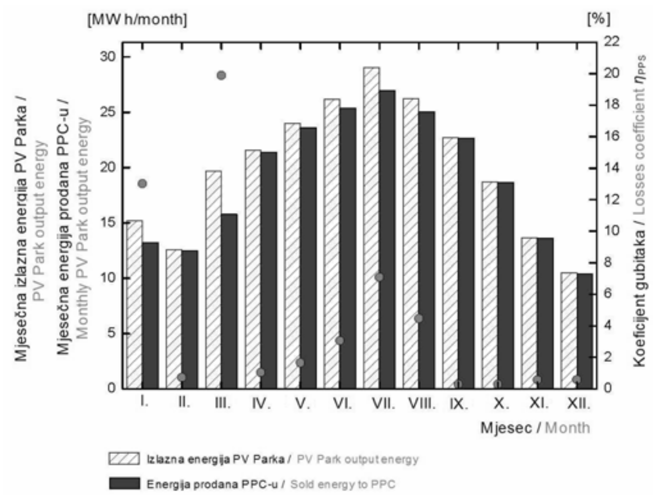
Gubici pretvorbe invertera [pretvaranje istosmjerne struje (DC) u izmjeničnu struju (AC)] određeni su na temelju 10-minutnih podataka oduzimanjem izlazne DC snage grupe FN panela od izlazne AC snage te normaliziranjem gubitaka od DC ožičenja i međuspoja (η_{net} = 6 %) i gubitka transformatora (η_{tr} = 2 %).

a 5 % mismatch compared with the real recorded output power was observed. This mismatch can be attributed to the PV panel degradation losses (η_{deg}) during ageing, as the PV Park has been in full operation since 2002. This is in full agreement with experimental studies and manufacturers declarations and warranties, whereas the initial power declarations lie at 5 % with a lifetime maximum of 20 % [8].

The inverter [direct current (DC) to the alternating current (AC)] conversion losses were calculated with a 10 minutes frequency by subtracting the array DC output power from the AC output power, and by normalizing the DC wiring & interconnection losses (η_{net} = 6 %), and the transformer losses (η_{tr} = 2 %).

Prema tome, izračunati gubici invertera (η_{inv}) zbrojeni su na 7,84 %. Konačno, gubici od mjesečne raspoloživosti i priključivanja nacionalne mreže (η_{ppc}) izračunati su kao omjer prodane energije PPC-u podijeljene ukupnom izlaznom AC energijom parka, kako je prikazano na slici 6.

Therefore, the calculated inverter losses (η_{inv}) are summed to 7,84 %. Finally, the monthly availability and national grid connections losses (η_{ppc}) were calculated as the ratio of energy sold to the PPC divided by the AC overall output energy of the park, and are shown in Figure 6.



Slika 6 — Mjesečna izlazna energija FN parka, mjesečna energija prodana PPC-u, i koeficijent gubitaka od raspoloživosti i priključivanja nacionalne mreže (η_{PPC})

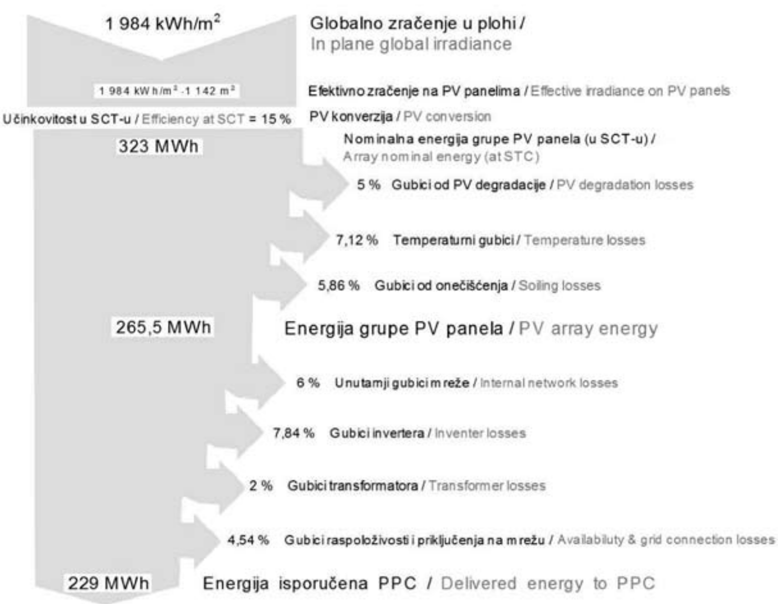
Figure 6 — Monthly FN Park output energy, monthly sold energy to PPC, and availability and national grid connections losses coefficient (η_{PPC})

Gubici od neraspoloživosti mreže i priključka (η_{PPC}) kreću se od 0,3 % (listopad i studeni) do 19,9 % (ožujak), uz godišnji prosjek od 4,54 %. Gubici su vrlo niski (<1 %) u veljači, travnju, rujnu, listopadu i prosincu, rastu od svibnja do srpnja, dok su za siječanj i ožujak krajnje visoki. Za sada se ti podaci ne mogu objasniti, jer nema podataka za razdoblja mirovanja mreže. Međutim, može se pretpostaviti da u siječnju i ožujku ima značajno razdoblje kada mreža odbacuje energiju iz parka. Ovo je značajna karakteristika ako se uzme u obzir da je autonomni elektroenergetski sustav Krete najveći sustav u Grčkoj s najvišom nacionalnom stopom rasta potražnje za elektroenergijom [2].

Razni godišnji gubici FN parka mogu se sabrati u Sankeyevu dijagramu na slici 7.

The availability and grid connection losses (η_{PPC}) range from 0,3 % (October and November) to 19,9 % (March), with an annual average of 4,54 %. The losses are very low (<1 %) in February, April, September, October and December, there is an increase from May until July, whereas for January and March the losses are extremely high. The data cannot be explained at present, since there are no available data for the grid off periods. Nevertheless, it can be postulated that in January and March, there is a significant period, where the grid rejects the power input from the park. This is an important feature, taking into account that Crete's autonomous electrical system is the largest one in Greece with the highest rate of increase nationwide in energy and power demand [2].

The various annual losses of the PV Park can be summarized in the Sankey diagram of Figure 7.



Slika 7 — Sankeyev dijagram proračunatih gubitaka u FN parku; parametri u podebljanom fontu izvedeni su iz stvarnih mjerenja u okviru analize neobrađenih podataka

Figure 7 — Sankey diagram of estimated losses in the FN Park, the parameters in bold are derived from the real measurements raw data analysis

4 ZAKLJUČCI

Prezentirano je prvo dugoročno praćenje i analiza rada jednog FN sustava priključenog na mrežu na otoku Kreti. Moguće je donijeti sljedeće zaključke:

— prosječna godišnja proizvodnja energije FN parka u 2007. godini iznosi 1 337 kWh/kWp,
— prosječni godišnji stupanj djelovanja parka iznosi 67,36 %,
— prosječni godišnji faktor angažirane snage iznosi 15,26 %.

Zaključci u ovom prikazu, u svjetlu nedavno najavljenog plana instaliranja fotonaponskog parka snage 50 MW u megalopolisu Grčke, od velikog su značaja.

4 CONCLUSIONS

The first long term monitoring and performance analysis of a grid connected PV system in the island of Crete has been investigated. The following conclusions can be drawn:

— average annual PV Park energy output in 2007 is 1 337 kWh/kWp,
— average annual performance ratio of the park is 67,36 %,
— the average annual capacity factor is 15,26 %.

The conclusions herein, in view of the recently announced plan to install a 50 MW photovoltaic park in Megalopolis Greece, are of great importance.

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