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Research Article

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Performance Comparison of Four Technologies of On-Grid PV Solar Systems under Baghdad Climate during February

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Abstract: All solar photovoltaic technologies studied in this research are located in Baghdad city at coordinates (33.33 °N, 44.43 °E, and 41 m above sea level). These technologies are 5 kWp Mono-Si, 107 kWp poly-Si, 15 kWp HIT, and 5 kWp CIGS. CIGS is the second generation while mono, poly, and HIT Si are the first generation. The energy production during February for CIGS, HIT, Mono-Si, and Poly-Si was 642.41 kWh, 1835.2 kWh, 542 kWh and 11174 kWh, respectively. The efficiencies of CIGS, HIT, Mono-Si, and Poly-Si were 12.6%, 14.6%, 10.2%, and 13.2%, respectively. The performance ratio for CIGS, HIT, Mono-Si, and Poly-Si were 83%, 83.3%, 74%, and 75%, respectively.

Keywords: Grid tied; CIGS; Mono-Si; Poly-Si; HIT.

1. Introduction

Solar energy has become widely used as an alternative energy source because it is environmentally friendly, clean, and a safe energy source [1]. The increasing energy demand caused by the rapid population increase has become a challenge due to the gap between electricity consumption and production, creating a problem in distribution time, budget, and environmental protection [2]. In terms of pollution, there has become a serious challenge represented by pollution due to the increase in pollutants released into the atmosphere, which in turn affects humans in two ways. The first causes many diseases such as cancer and others, and the second is that these pollutants globally cause the phenomenon of global warming that threatens humanity and the ecosystem in general. All the above problems, especially pollution, can be solved by relying on renewable energy. There is good solar radiation in Iraq, about 2000 kWh/m^2/year. This amount could enable the production of a large solar photovoltaic power plant, where photovoltaic solar panels are created from semiconductors that allow converting sunlight into electricity. These PV modules can supply electricity with a safe, reliable and environmentally friendly power source in the long term. The efficiency of solar photovoltaic systems depends on a number of influences, namely environmental conditions and system design, which can have a significant impact on the efficiency and quality of the energy response of the entire system [3]. The main goal of an on-grid photovoltaic system is to produce the largest possible amount of energy.

Therefore, the energy generated by photovoltaic systems is considered the standard that judges the efficiency of this system. Grid-connected solar PV systems have grown at an annual rate of 40% over the past decade rising from 0.2 GW at the beginning of 2000 to 21 GW at the end of 2009 [4,5]. More research has been done, in many places around the world, on analyzing the performance and characteristics of grid-connected solar PV systems. For example, Li studied a grid-connected PV system in the city of Hong Kong and demonstrated that the energy payback period was calculated to be approximately 8.9 years. [6]. Canetti et al., studied four different panel technologies, such as CdTe, a-Si, polycrystalline silicon and microcrystalline silicon, estimated the incident solar radiation for a year in Spain and showed that thin films were more productive than other panels [7]. Jawad et al., evaluated the use of photovoltaic panels in 5 different places in the city of Baghdad, and showed that the photovoltaic panels in agricultural areas were less affected by dust, while densely populated places were more affected by pollution [8]. Adaramola et al., studied the effect of relative humidity on the performance ratio of a solar photovoltaic system, and the results showed that the energy productivity of photovoltaic cells increases as the relative humidity decreases [9].

2. PV Solar System Details

All solar photovoltaic technologies studied in this research are located in the city of Baghdad at coordinates (33.33 °N, 44.44 °E, and 41 m above sea level). These technologies are 5 kWp Mono crystalline-Si, 100 kWp poly crystalline-Si, 15 kWp HIT, and 5 kWp CIGS. CIGS is the second generation but mono, poly and HIT Si are the first generation, as shown in table 1.

Table 1. Solar PV system characteristics.

PV module model	TS-165C2 CIGS	MCM 180-Mono	HIT-205NHE1	Poly-ZS-340P-72
Number of panels	30	28	72	355
Inverter model	SMA SB-5000T-21	SB5.0-1AV-40	Sunny Tripower, 15000TL-10	STP 25000TL-30
Inverter Size (kWp)	5.30	5	15	100
Inverter efficiency	97%	97%	98%	97%
System Size (kWp)	5	5	15	100
Tilt Angle	45°	40	30°	15⁰

3. Performance Analysis

Performance can be evaluated regarding system efficiency, performance ratio, and energy produced. Performance ratio and system efficiency regardless of the inclination angle [10].

3.1. Energy Produced

Total power is the amount of AC (alternating current) power produced by a system for a specified period. The hourly, daily, and monthly energy product is calculated respectively as follows [11, 12]:

$$E_{AC,h} = \sum_{t=1}^{60} \mathbf{EAC,t} \quad (1)$$

$$E_{AC,d} = \sum_{h=1}^{24} \mathbf{EAC,h} \quad (2)$$

$$E_{AC,m} = \sum_{d=1}^{N} \mathbf{EAC,d} \quad (3)$$

Where: EAC,t is the AC power produced in minutes; EAC,h is the AC power produced per hour h; EAC,d is the AC power produced daily; EAC,m is the AC power produced monthly and N represents the number of days in a month.

3.2. Performance Ratio (PR)

PR displays all the effects of losses on the rated (nominal) power product of a solar PV system. The PR value shows how close the real system performance is to the ideal performance under actual working conditions and allows comparison of solar PV systems regardless of inclination angle, orientation, location and rated power capacity [13]. PR can be given as follows:

$$\boldsymbol{PR} = \frac{\textbf{Actual reading of plant output in kWh.p}}{\textbf{Calculated,nominal plant output in kWh.p}} \quad (4)$$

Nominal power plant output **=** Annual incident solar irradiation at the surface of the PV plant **x** nominal efficiency of the PV plant modules.

3.3. System Efficiencies

Efficiency can be calculated on an annual, monthly, daily و and hourly basis. The system efficiency (ηsys) is based on the AC power product [14]. System efficiency is the ratio of the average (daily, monthly, or annual) power output (AC) to the total average (daily, monthly, or annual) in-plane solar irradiation multiplied by the area of the solar PV array [15].

4. Results and Discussion

Figure 1, shows the productivity of solar photovoltaic energy systems during February of 2019. The comparison between the systems' production is made by comparing each system with its nominal production because the four different systems have different power capacities. The productivity of the lager system (100 kWh) reached 11,174 kWh, with its nominal production (output) reaching 14,860 kWh, meaning a loss of 3,686 kWh (25%), while the productivity of the HIT system was 1835.2 kWh, while its nominal productivity is 2203 kWh, i.e. the loss. 368 kWh (17%). The productivity of the CIGS system was 642.2 kWh, while its nominal productivity was 787.1 kWh, meaning a loss of 145 kWh (18%). The productivity of the Mono-Si system was 540 kWh, while its nominal value was 729 kWh, meaning that it lost 189 kWh (26%). This means that the best solar PV system is HIT because it has lower losses. Because HIT technology is less affected by weather factors than other technologies.

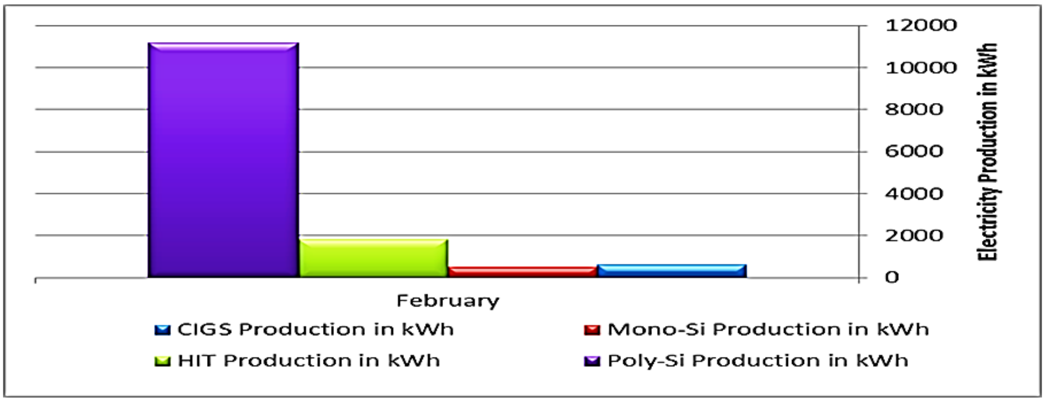

Figure 1. Solar PV systems productivity.

Figure 2 shows the average daily production of the systems in February. It is noted that there is an increase in production over time until 12:00 pm (peak solar radiation), and then it begins to decrease with sunset. It was also noted that the production of the CIGS system is greater than the Mono-Si system even though they have the same power (5kWp). In figure 2, the production of HIT, Mono-Si, and Poly-Si starts at 7 am, but the production of the CIGS system starts at 8 a.m. due to the shadow effect on the CIGS system.

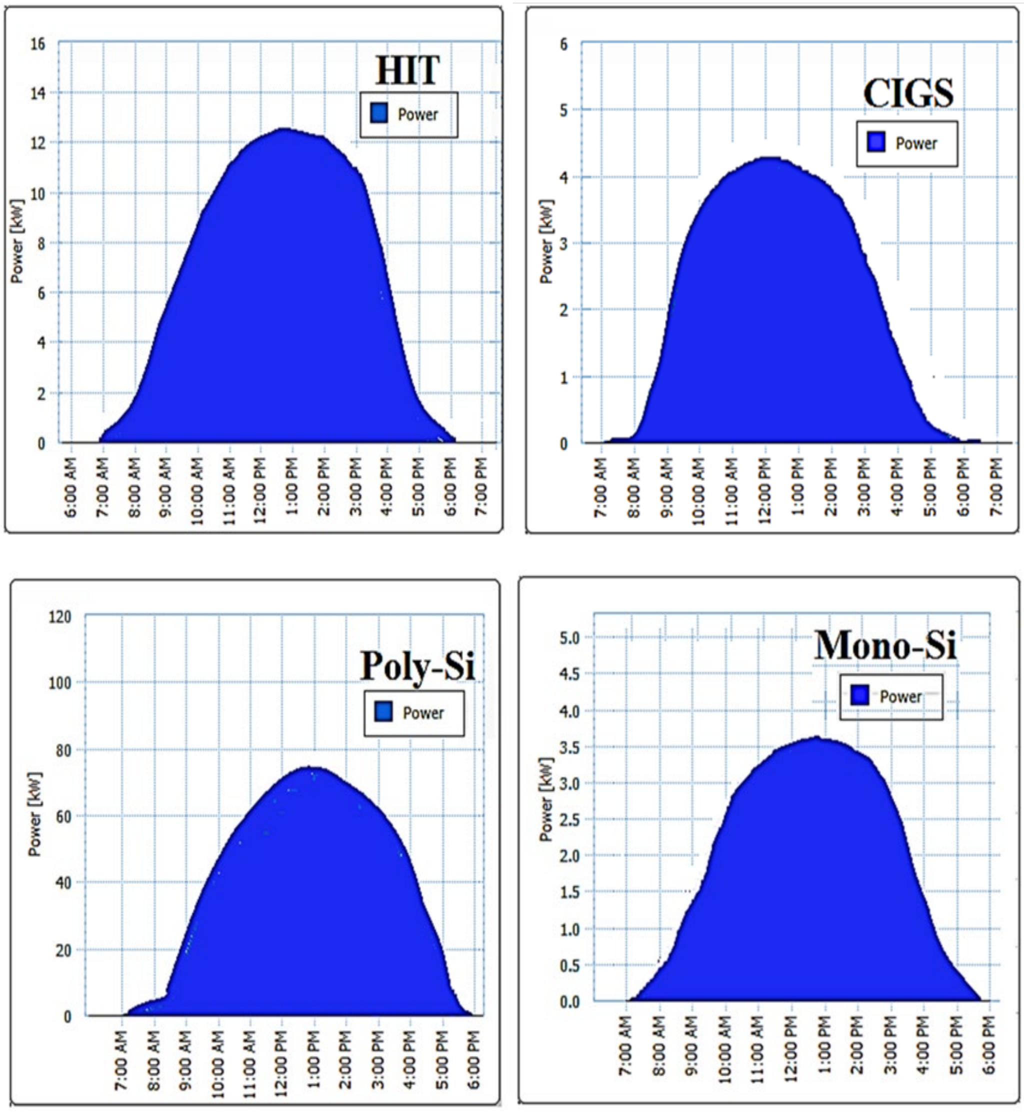

Figure 2. Daily average of systems production in February month.

Figure 3 illustrates system efficiencies during February month, where the actual and nominal (nom) efficiencies of HIT, CIGS, Mono-Si and Poly-Si were (14.6% and 16%), (12.6% and 15.4%), (10.2 % and 14.2%), and (13.2% and 17.5%), respectively. Here, HIT lost 1.4% of its nominal efficiency, CIGS lost 2.8% of its nominal efficiency, Mono-Si lost 4% of its nominal efficiency, and Poly-Si lost 4.3% of its nominal efficiency during this month.

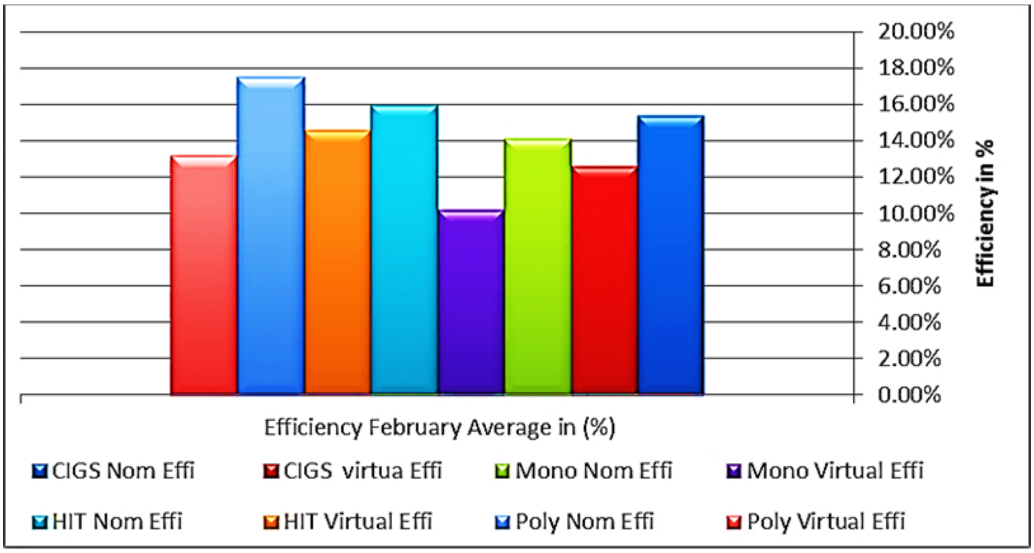

Figure 3. Illustrates system efficiencies during February month.

Figure 4 shows the performance ratio (PR) of four solar PV systems. The best PR was for CIGS and HIT at 83% each, but the lowest PR was for Mono-Si and Poly-Si at 74% and 75%, respectively. The performance ratio values show all the losses experienced by a solar PV system. PR allows comparison of different solar PV systems regardless of solar radiation, tilt angle, direction angle, location and rated power.

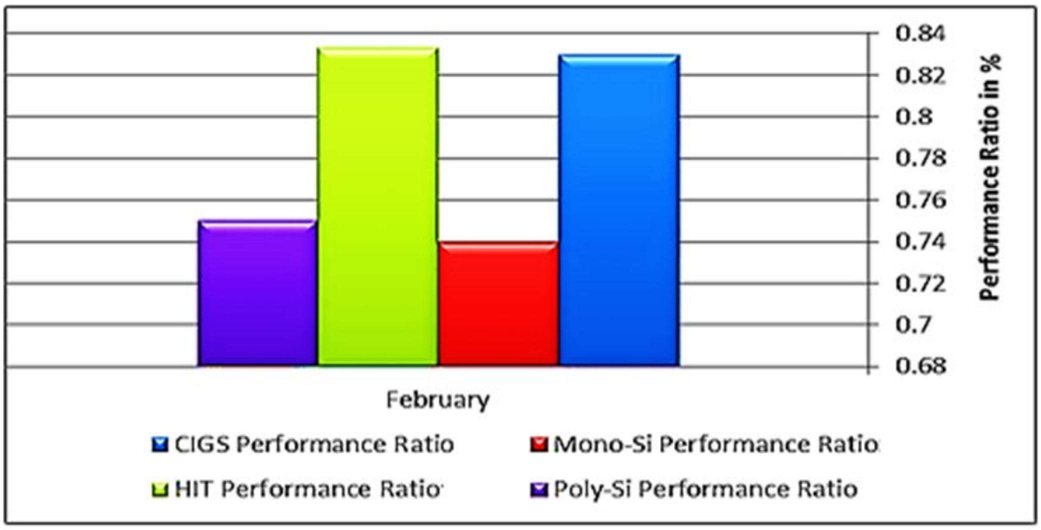

Figure 4. Performance ratio of four solar PV systems.

5. Conclusions

The first-generation technology (silicon) loses more electrical energy than the second-generation technology (CIGS) and HIT technology because it is greatly affected by air temperature. The efficiency of CIGS and HIT technologies is less dropping than Mono and Poly-Si because HIT and CIGS technologies are less affected by weather factors than other technologies. CIGS and HIT have higher PR performance than Mono and Poly-Si because their temperature coefficient is lower than Mono-Si and Poly-Si (silicon). That is, CIGS and HIT are less affected by ambient temperature than Mono-Si and Poly-Si. CIGS (thin film) technology is cheaper than the other technologies mentioned above and is less affected by air temperature and therefore more suitable for the hot Iraqi climate and the Arabian Gulf.

Supplementary Materials:

Author contributions

Alaa N. Abed is the one who designed the work. Naseer K. Kasim and Alaa N. Abed conducted the experiments. Alaa N. Abed edited the manuscript. All authors have read and approved the final version submitted to the journal.

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Conflict of interest

The authors declare no conflict of interest.

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