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Performance evaluation of photovoltaic systems on Kuwaiti schools' rooftop

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ABSTRACT

Photovoltaic (PV) is a high-potential renewable energy technology for Kuwait to pursue due to high daily irradiation, and has garnered local attention in recent years due to the growing energy demand and concerns over climate change. As yet, no data are available regarding the actual performance of PV systems in Kuwait's harsh environment. This paper presents a 12-month-long performance evaluation of the first 85.05 kW_p and 21.6 kW_p copper indium gallium selenide (CIGS) thin film, grid-connected PV systems on the rooftops of two schools. The schools' monthly energy consumption and PV generation profiles, the actual performance of the PV plants, the effectiveness of automated cleaning systems on the power output, and the benefits of PV implementation in schools were analyzed and evaluated. Data analysis was applied to filter and normalize the data in order to identify the actual performance parameters. The findings of the study, based on solar irradiation collected, the performance of the module technology and the effectiveness of the automated cleaning systems, show that the performance ratio was maintained between 0.74 and 0.85. Furthermore, the minimum monthly energy yield of the PV systems was about 104 kW h/kW_p. The annual average daily final yields of the PV systems in this study were 4.5 kW h/kW_p/day. The results provided insight into the performance of CIGS grid-connected PV systems in Kuwait, and those data will be beneficial to the PV research community worldwide. School buildings, particularly for the rooftops, are a unique and important asset for urban PV system implementation, because they provide a combination of relatively large, unused, suitable areas, which would make distributed and effective solar power generation possible on the national level.

1. Introduction

Kuwait is situated on the northwest part of the Arabian Peninsula, bordering the Arabian Gulf, between 28° and 30° latitude and between 46° and 48° longitude. The country experiences frequent dust storms and very low rainfall due to its desert climate conditions and sandy, flat terrain. It was reported that the average number of dusty days in Kuwait is 255.4 days/annum [1]. The maximum annual dust fallout was reported to be 112 ton/km^2 [2]. Kuwait's economy and energy-production are both oil-based. Alternative energy sources, such as solar energy, have to be introduced to supplement local electricity demand because the rapid growth of energy consumption is estimated to be around 7% per year since 1991. This fast growth is inflicting a huge strain on the national budget and local environment as most of the electricity is produced from oil. As a result, the country would occasionally face serious electricity shortages during the summer months, which has led the electricity provider to carry out organized electrical blackouts. Building more power plants will not solve this problem since there is a large swing in electrical demand between summer and winter, which was reported to range between 50% and 60%. The large seasonal variation in energy demand is mainly due to air conditioning load during the hot summer months. This challenge caused the Ministry of Electricity and Water (MEW), the sole utility responsible for generation and distribution of electrical power, to consider unconventional electricity generators. In 2012, the Emir of Kuwait, Sheikh Sabah Al Ahmad Al Sabah in his opening ceremony for the United Nations' 18th Conference for Climate Change announced that 15% of the total energy generation for Kuwait is expected to come from renewable energy sources by the end of 2030. To that end, in this work, the Kuwait Institute for Scientific Research (KISR), investigated the utilization of solar photovoltaic generators on school rooftops to effectively harness this source of energy. Kuwait's annual global irradiation is around 2088 kW h/m^2. Photovoltaic (PV) technology is considered to be one of the most promising types of renewable energy technologies for the country to pursue, and has garnered

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local attention in recent years due to its significant price reductions and the modular nature of the technology, which allows users to install from as little as a few hundred watts to hundreds of mega watts.

The KISR studied the load profile in Kuwait for different buildings; a daily peak-load between 3 and 6 PM in the summer season was identified. [3]. Furthermore, the loads of different buildings and their load profiles were also identified. It was recognized that school buildings have the best potential for energy efficiency applications and provide the best roofs for PV system installations. The schools in Kuwait possess two main characteristics, making PV system integration have better synergy compared to other buildings. The schools have relatively large unoccupied roofs, and electrical demand for schools tends to be much different than the national peak demand. This would translate into a higher solar energy contribution with respect to the buildings' annual energy consumption and also the ability to export to the grid during peak demand, when energy is much needed by the network on the national level. This study was also motivated by the lack of data on the performance of PV systems in Kuwait's specific climate and by the need to explore practical methods for PV module cleaning.

The performance of a PV system depends not merely on cell technology, geographic position and installation configuration, but also on environmental parameters, such as global irradiance, ambient temperature, and soiling loss. Observing the performance of the PV system with respect to temperatures and soiling was one of the objectives of this work. The effects of various climatic conditions and different geographical locations have been reported in several publications [4–6]. Thin film technology specifically was reported to have more resilience to temperature and soiling losses [7,8]. In a study carried out in India's arid environment, performance loss due to dust accumulation was investigated for three types of PV modules; monocrystalline silicon with a glass surface, polycrystalline with an epoxy surface and an amorphous silicon panel with glass. Researchers conducted the test for 4000 s (1.1 h), and their results showed less reduction in performance from the amorphous module and greater reduction from the polycrystalline, compared to the other two types [9]. Multiple studies have been performed to analyze factors that affect PV performance; one of the most impactful of these factors is dust deposition, or 'soiling'. It is obvious that any change in irradiance intensity or quality should affect a PV system's performance; therefore accumulation of dust, in the form of organic or non-organic particles, will influence the characteristics of the solar irradiations reaching the PV module. One problem with available literature is that the results are highly dependent upon location. The presence or lack of natural cleaning elements (such as rain), combined with the topographical layout, can greatly affect how soiling alters a PV system's performance at a particular site [10].

In another study in Riyadh, Saudi Arabia, over the course of eight months, as much as 32% of potential output was lost from the modules when left unclean [11]. Dust storms are particularly impactful, and can cause up to 20% loss during one event. According to a study in Dhahran, Saudi Arabia, over a period of six months, during which modules were not cleaned, up to 50% losses were measured [12]. Clearly, while routine cleaning can improve the panels' performance, it is necessary to be able to alter cleaning schedules to suit climate conditions, especially in the Gulf Region, where sandstorms and the rates of soiling are relatively high. Furthermore, natural cleaning methods cannot suffice to remove the rapid accumulation of dust [13]. In the United Arab Emirates (UAE), up to 70% of power was lost to soiling, due to a 10% monthly rate of decline in output during summer months and a 6% decline rate during the winter [14].

As for cleaning frequency and how it should be done, this is also highly site-specific. One study strongly suggested that cleaning occurs at a minimum frequency of no less than every 2–3 wk in the absence of a cleansing rain. Over the course of that study, modules that were left unclean declined by 2.2% for monocrystalline, 2.5% for polycrystalline, and 1.7% for amorphous silicon panels after a single week, when compared to those of the same type which were cleaned regularly. It was recommended that a cost/benefit analysis be performed for any system to determine its specific needs in terms of a cleaning schedule [10]. In Abu Dhabi, it was suggested that monthly cleaning would be sufficient. This study also revealed that July was the worst month for soiling with losses of about 27% in productivity [14]. In the southern desert of Libya, the months from February to May are considered to be the worst in terms of soiling, due to seasonal winds, which deposit anything from sand to plant detritus onto the PV modules, negatively impacting their output in what is otherwise an ideal climate in terms of insolation. Weekly cleaning however, minimized these losses to 2–2.5% [15]. Research in Santa Clara, California, found that the dry season is most likely when losses will be realized, with a drop in productivity from 7.2% to 5.6% in efficiency; this was deemed to be greater than any expected decrease due to normal degradation. After rain occurred in the autumn, the efficiency returned to 7.1% [16]. Additionally, the type of technology utilized is important to factor in when predicting the effects of soiling, as the spectral transmittance of each is realized differently. A previous study in Kuwait revealed that a-Si and CdTe modules with a higher band gap (300–800 nm) experienced greater losses (33%) when compared to c-Si and CIGS (28.6% and 28.5%, respectively) under the same conditions. Another factor to consider in terms of dust accumulation is the tilt angle of the panels; in this particular study, it was revealed that the optimum tilt angle (30°) was also the angle that had the highest variation of dust accumulation (1.87 mg/cm^2) [17]. In a report published by the Environment Canada (2012), the performance ratio for rooftop PV systems was 0.75 and 0.8 for ground-mounted, and the average PR values were given for three PV technologies; CIGS at 0.84, double junction a-Si at 0.82, and micromorph at 0.81 [18]. Over the last 20 years, the statistical average performance ratio of a new PV installation in moderate climates has improved from 0.65 to approximately 0.85 [19].

In order to obtain data specific to Kuwait, this study investigated the performance of two small-scale, grid-connected PV systems consisting of CIGS thin film. These two systems were installed on the rooftops of Azda and Sawda schools, as shown in Fig. 1.

2. Photovoltaic plants' description and methodology

The two PV systems were installed on the rooftops of Sawda and Azda Schools. The neighboring schools are located to the southeast of Kuwait City, and the PV systems are mounted approximately 110 m away from each other. Typically, schools' rooftops are relatively large with significant empty space where PV systems can be installed. The data acquisition system consisted of Sunny Boy inverters, Sunny SensorBox and Sunny WebBox. The Sunny SensorBox was used to measure in-plane total solar radiation (from a reference cell) on the PV modules. Additional sensors for measuring the ambient temperature, wind speed, and temperature at the back of one of the PV modules were connected to the SensorBox. The solar radiation data from the site was cross-checked with a pyranometer (KIPP & ZONEN, CMP21) set at 20°, identical to the tilt angle of the solar array, and located at a nearby site. The monthly solar radiation data measured is presented in Fig. 2.

The monitoring system logs the power output, energy output, ambient temperature, and module temperature at five-minute intervals. Data were collected over a twelve-month period and