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Cloud Effect on Power Generation of Grid Connected Small PV Systems

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Abstract**—**Photovoltaic (PV) power generation systems, mainly small scale, are rapidly being deployed in Jordan. The impact of these systems on the grid has not been studied or analyzed. These systems can cause many technical problems such as reverse power flows and voltage rises in distribution feeders, and real and reactive power transients that affect the operation of the transmission system. To fully understand and address these problems, extensive research, simulation, and case studies are required. To this end, this paper studies the cloud shadow effect on the power generation of a ground mounted PV system installed at the test field of the Renewable Energy Center at the Applied Science University.

Keywords**—**Photovoltaic, cloud effect, MPPT, power transients.

I. Introduction

GRID connected photovoltaic (PV) power generation systems are being rapidly deployed in Jordan [1]. Currently most of these are small-scale systems, under 1MW. In addition, large-scale projects are currently planned and will be installed in the near future. Distribution systems are typically designed for delivering electric energy to end-use customers, rather than for collecting it from distributed energy resources. As a result, a variety of technical issues related to PV system integration is expected to arise. To fully understand and address these problems, extensive studies are required. The variability of distributed power generation under all possible environmental conditions should be carefully accounted for. Variably cloudy conditions produce erratic variations in solar irradiance and PV power production. The volatility of PV power generation under these conditions may lead to unfavorable operating conditions and power system failures. This paper studies the variations in power generation induced by cloud cover for a grid-tied system installed at the Applied Science University campus in Amman-Jordan.

II. Location

The Applied Science University is located in the Northern section of the Amman City, the capital of Jordan. The system represents one component of a test field containing multiple renewable energy systems for the purpose of collecting real-time data, comparing the performance of different systems, and conducting experiments and research projects. This test field is a part of the renewable energy center located on the university campus [2], [3].

III. PV System

The experiment was conducted on a grid-tied 5 kWp ground mounted shadow free system. The system is south-oriented at a tilt angle of 11^o which is not the optimal angle for this location according to calculations is 28^o. However, the selection of 11^o angle was based on the widespread of rooftop PV systems in residential and commercial buildings where the available area is the most critical factor in the design of such PV systems. Table I gives the basic system specifications [2], [3].

TABLE I
FIVE KWP PV SYSTEM SPECIFICATIONS

Panel Model	Number of panels	Inverter type	Inverter Size (kW)	Capacity (kWp)
Yingli YL250P-29b	20	SMA SB5000T L-21	5	5

IV. I-V Characteristics

In order to understand the relationship between changes in solar irradiance and changes in PV generated power, firstly we need to understand the basic operating characteristics of photovoltaic panels.

The measured irradiance for the non-shaded module was 965 W/m^2 and the measured irradiance for the totally shaded module was 165 W/m^2. The measured cell temperature at the front surface of the module was 36 C^o and 34 C^o for the non-shaded and the shaded module, respectively. The recorded wind speed at 1.5 m high from the ground surface was 1.2 m/s and the time of the experiment.

V. Solar Irradiance Transients

Weather often brings much variation and uncertainty. Solar irradiance is very much affected by changes in weather. PV power fluctuations are referred as PV Power Transients. Sunny days produce large solar irradiance values while cloudy days limit the available solar irradiance. Hence, clouds have a large impact on the solar irradiance received by a solar panel array. Determining the speed at which solar irradiance changes over time provides useful information for better comprehending how quickly PV power would drop if exposed to such solar irradiance changes [4].

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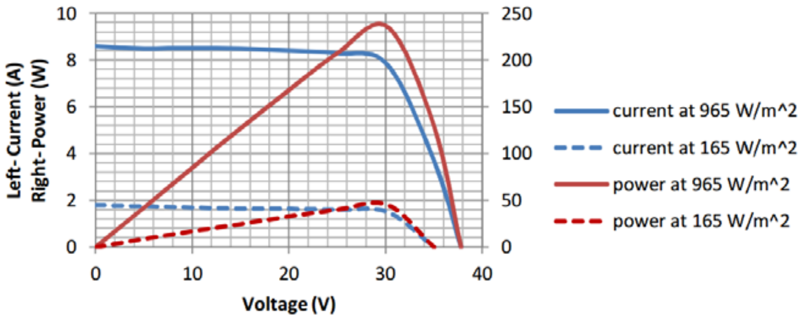

Fig. 1 Measured I-V and power curves for the PV panel without shading, 965 W/m^2, and with total shading effect at 165 W/m^2

VI. Clouds Shadow Effect

Any change in solar irradiance will affect not only the output power of a PV module, or PV string, but also the power supplied by the grid-connected inverter. The majority of grid-connected PV systems operate with maximum power point tracking control systems (MPPT). Mainly, this system is integrated within the inverter for the purpose of ensuring that the PV system operates at a point that produces maximum power generation. However, maintaining a PV array near its MPP is a difficult task when weather conditions lead to variations in solar irradiance [4], [5]. In addition, quick solar irradiance changes can possibly lead a PV system to operate at voltage levels outside the inverter's DC operating range. This scenario can force the inverter to shut down and discontinue supplying power to the grid. As a result of such a scenario, large changes in PV output power can take place from simultaneous inverter tripping. Such inverter-tripping-induced PV power changes often exceed the size and severity of any cloud-induced PV power fluctuations [6], [7].

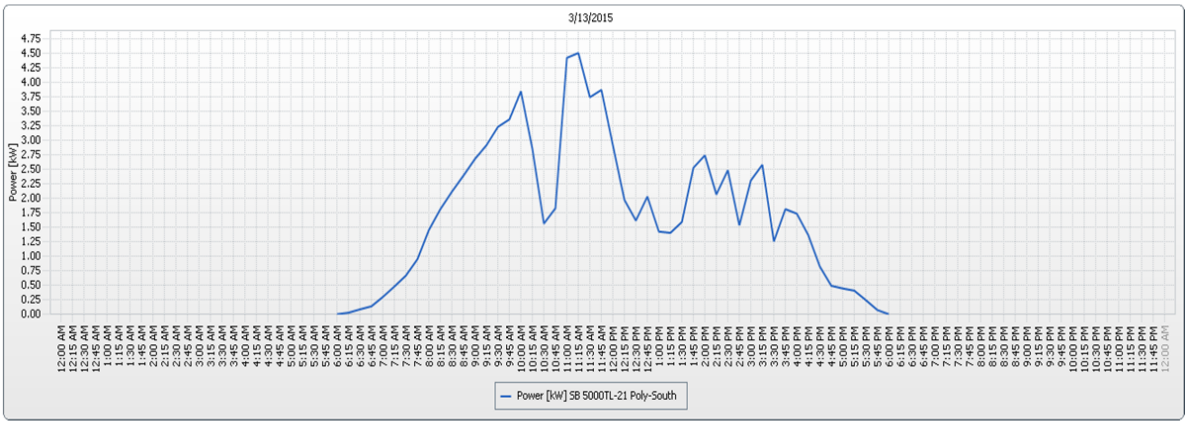

Fig. 2 Power output (kW) on the 13th of March 2015

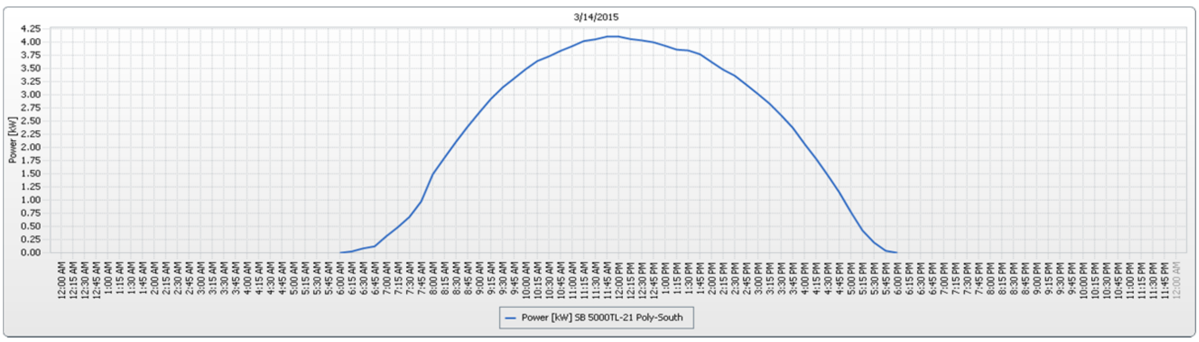

Fig. 3 Power output (kW) on the 14th of March 2015

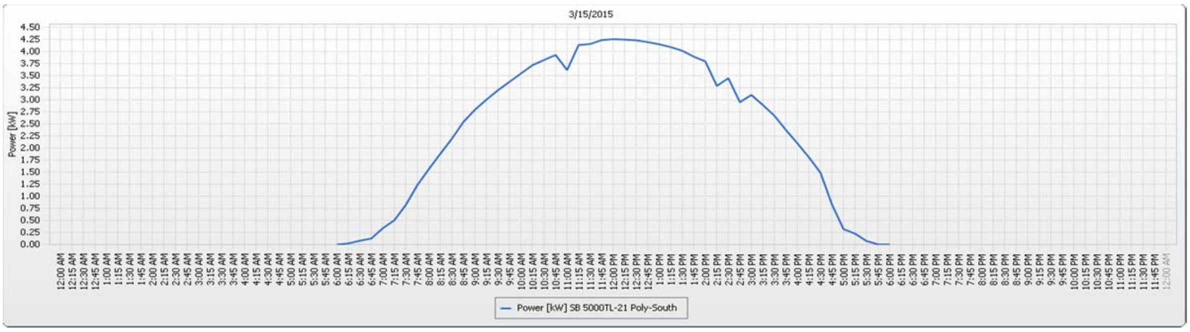

Fig. 4 Power output (kW) on the 15th of March 2015

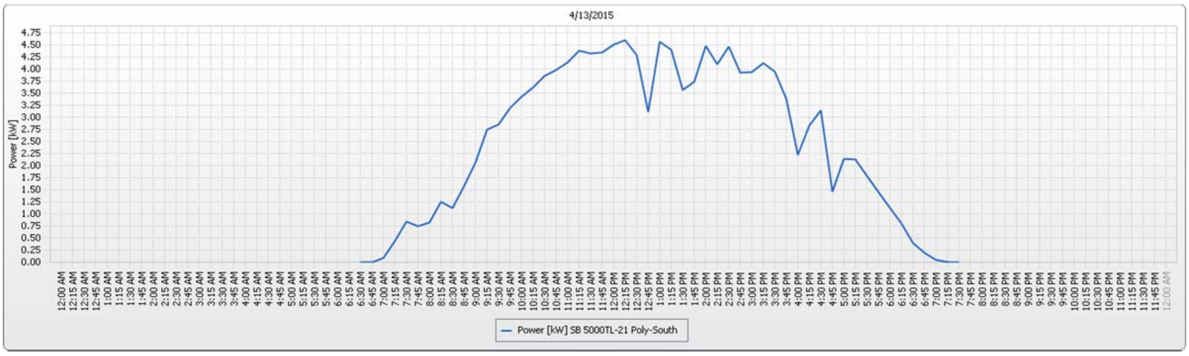

Fig. 5 Power output (kW) on the 13th of April 2015

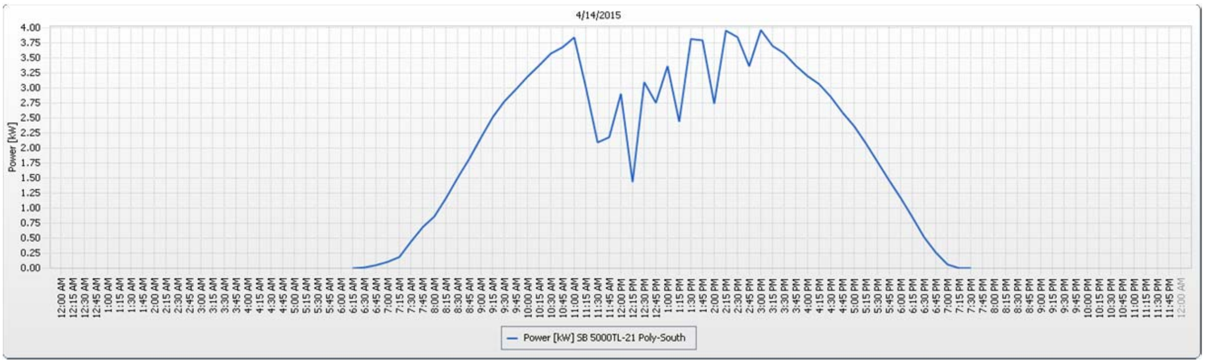

Fig. 6 Power output (kW) on the 14th of April 2015

VII. Results and Discussion

Direct data was collected from the 5 kWp system. The data was collected at the output of the grid-connected inverter, therefore representing the actual AC power delivered to the grid. The sample data was collected for three days the 13th, 14th, and 15th of the month for four months; March, April, May, and June to study the effect of cloud shadow on the power generated.

On the 13th of March, shown in Fig. 2, the effect of clouds' induced shadow is clear, and the associated power fluctuations can be calculated at each time frame. There was a noticeable power drop during the time frame from 10:00 AM until 10:30 AM. The power dropped from 3.75 kW to 1.5 kW. The slope of the power drop is - 0.075 kW/min. During the time frame from 10:45 AM until 11:00 AM there was a rise in the power due to change in clouds' shadow intensity causing the power to change from 1.75 kW to 4.5 kW. The slope of the power rise is 0.1833 kW/min.

This rapid fluctuation in power with respect to time at a larger scale can lead to grid instability, consequently the sharper the slope the higher the instability. There were additional power fluctuations as can be seen from the power curve but with a small slope representing less of a challenge.

On the 14th of March, shown in Fig. 3, there was no noticeable shadow so the power curve was smooth and stable, on the 15th of March there was a change in the shadow intensity due to clouds between 10:45 AM and 11:15 AM with an associated power change from 3.87 kW to 4.125 kW within 30 minutes which does not present any instability on the grid.

For the month April, Figs. 5-7, It was noted on the 13th and 14th there was noticeable clouds especially on the 14th leading to high fluctuation in the power. On the 15th there was some cloud shadow but the power generation curve has lower fluctuations and is considered stable.

As shown in Figs. 8-13, the curves for the 13th, 15th of May and 13th, 15th of June show that the clouds shadow effect is negligible, but on the 14th of May the shadow effect is high between 1:00 PM until 3:15 PM leading to a significant change in power, also the 15th of June at 11:45 AM another problem. However, it is not clouds related rather it was due to a power shutdown from the grid causing the power output cutoff.

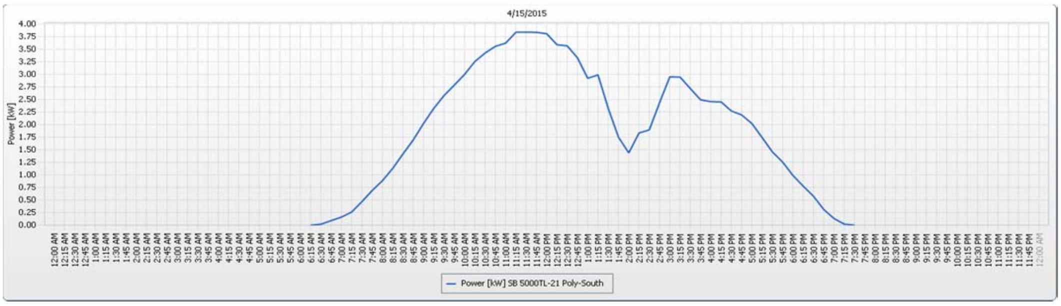

Fig. 7 Power output (kW) on the 15th of April 2015

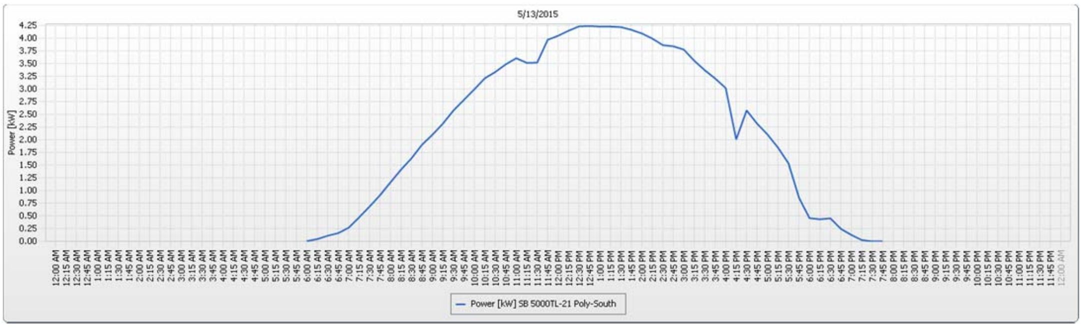

Fig. 8 Power output (kW) on the 13th of May 2015

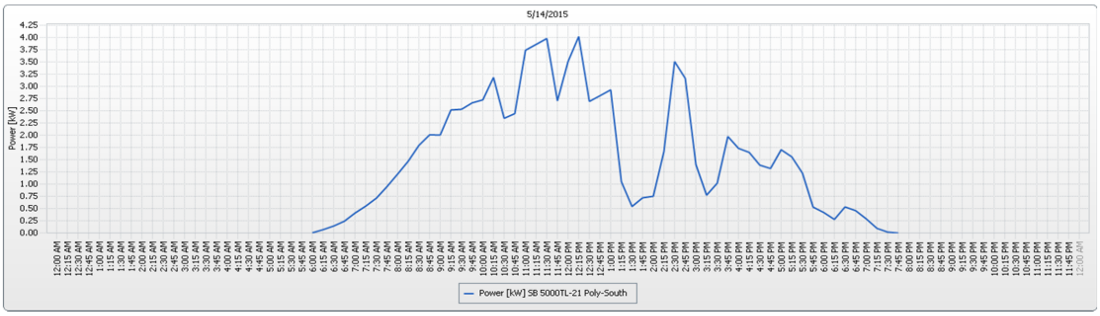

Fig. 9 Power output (kW) on the 14th of May 2015

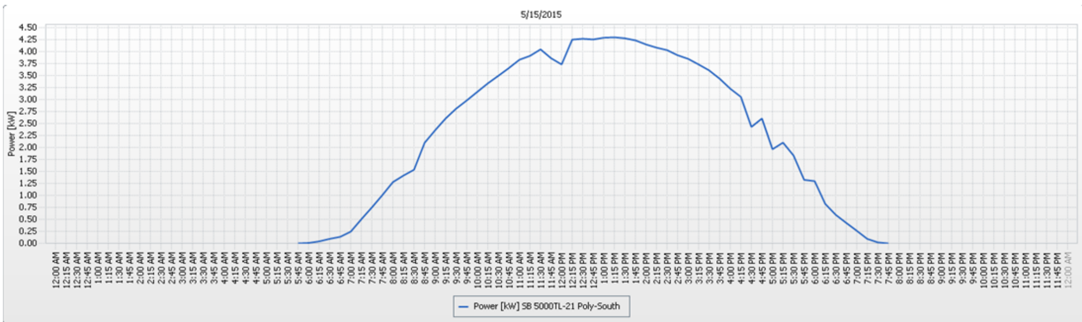

Fig. 10 Power output (kW) on the 15th of May 2015

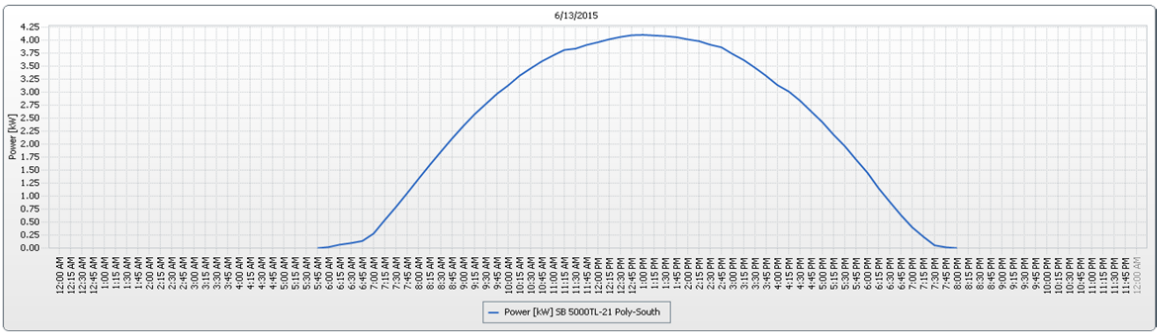

Fig. 11 Power output (kW) on the 13th of June 2015

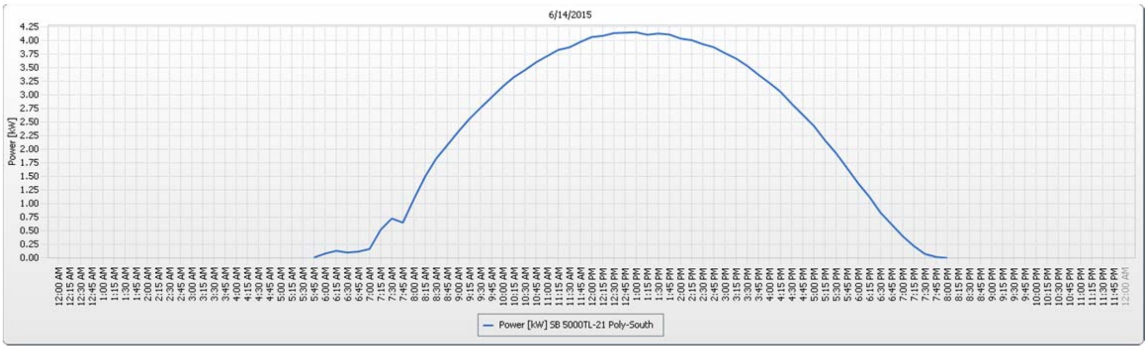

Fig. 12 Power output (kW) on the 14th of June 2015

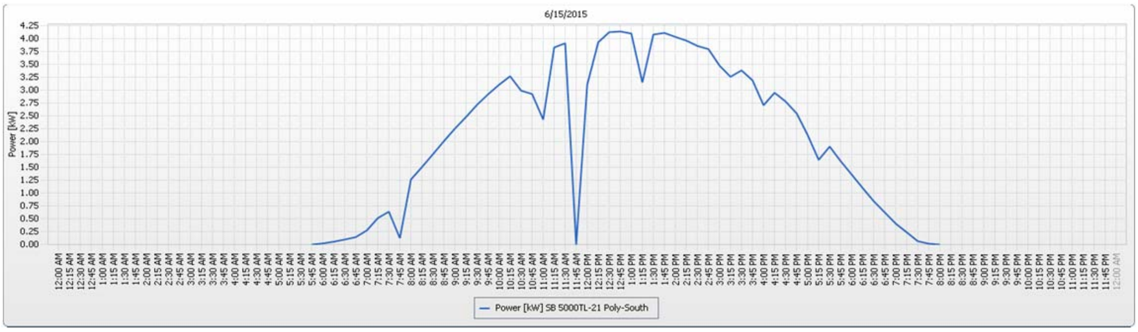

Fig. 13 Power output (kW) on the 15th of June 2015

VIII. Conclusion

The effect of clouds shadow on photovoltaic systems must be carefully taken into consideration in order to avoid grid instability issues. Power generation data was collected and analyzed so as to determine the maximum increase and decrease in power slopes over various time increments. Such maximum increase and decrease in slopes represent only a small change of larger, longer duration power fluctuations due to solar irradiance transients. These fluctuations can lead to various levels of grid instability depending on the size of the power plant and level of PV grid penetration. The rapid rise in power can be controlled by setting the system, mainly through the inverter, to gradually increase the power by certain fixed increments. However, power loss cannot be compensated by the system without the use of additional systems such as storage batteries.

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