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Potential effect of SARS-CoV-2 on solar energy generation: Environmental dynamics and implications

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ABSTRACT

The Covid-19 pandemic is exerting a significant influence on global energy markets, and continuing to hinder the growth of core technology for the implementation of renewable forms of energy. With an unprecedented effect, the new coronavirus, known as SARS-CoV2, has succeeded to seize the control of most cities of the world and led to their closure. The newly-emerged virus has also resulted in environmental changes. The present study was conducted to show the indirect positive effects of COVID-19 on the reduction of air pollution, particularly in countries such as Italy, France, and India. Our research proved the existence of meaningful relationships between probable actions, air quality improvement, and increased energy generation by photovoltaic systems (PVs).

Newly-obtained data from the Copernicus Sentinel-5P satellite illustrate that some cities have experienced a 45 to 50% reduction in nitrogen dioxide (NO₂) concentration compared to the same period in the past year. This reduction has provided two important and unexpected benefits, namely the reduction in environmental pollution (specifically air pollution) and, as a consequence, an increase in the amount of energy generated by PVs.

Introduction

Coronavirus disease 2019 (COVID-19) has spread around the world and become a serious infectious disease. It has tremendously affected human health worldwide. The devastating effects of this disease have been such that it has pushed most countries to the brink of bankruptcy. The first patient was hospitalised on December 12, 2019, following which millions of people began to be hospitalised [20]. Unfortunately, the death toll of this disease reached 250,000 by early May 2020. United States, Spain, and Italy were among the most affected countries with the highest number of casualties [9].

As a consequence of the coronavirus, the global green and clean energy scenario that has burgeoned in recent decades and enjoyed exponential development has been exposed to a significant threat [11]. The COVID-19 pandemic has struck the processing plants, supply chains, and green energy-related industries, and has slowed down the shift to renewables. In addition, well-established green energy policies, particularly those that burden sectors that are badly impacted by the crisis, are in doubt [8].

On the other hand, energy demand has increased during the last decades. Furthermore, concerning the threat of fossil fuel exhaustion, the focus has shifted to alternatives such as renewable energy sources (RESs) [5]. Among RESs, solar energy is a suitable choice for various types of applications because it can be directly converted to electrical energy using PVs. The PV power system (PVPS) is assumed as an attractive means to develop the RESs implementation [17]. This is an environmentally-friendly and long-lasting source that is free of maintenance and repair. The PVPS system consists of several PV arrays connected in series and parallel so that the required rated power could be extracted. Many efforts have been made to enhance the efficiency of these systems mainly to extract the maximum power point (MPP) from PVs [18]. Each solar cell has one unique operating point, so-called MPP. When the system is operating at this point, it presents the maximum power efficiency and output power. On the other hand, due to the changes to the output characteristics of the PV system caused by solar variations as a result of air pollution, temperature, and demand, these systems rarely operate at MPP.

The probability of occurrence of partial shading conditions (PSC) in

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this type of system is high. PSC occurs when PVPS faces non-uniform irradiance [12]. Ideally, the PV system should be installed in shadeless regions. However, they are mostly located in urban areas and may be exposed to the shade of buildings. Indoor shading conditions, the power-voltage (P-V), and power-current (P-I) curves of the PVPS system will contain several local peaks and one single global peak, where the global peak must be tracked. One of the important parameters that can play a critical role in the change of the maximum power is irradiance changes that typically occur due to air pollution [4].

Notwithstanding the spread of COVID-19 in Europe, the share of renewables was estimated to be 41 percent in the first three months of 2020 (16 percent higher than the amount produced in the first quarter of 2019) due to a steep drop in demand and prices [8]. The new pandemic has contributed to dramatic improvements in the PV system deployment and implementation. The ‘Butterfly Effect’ disruption will lead to negative and positive changes that will become more enduring features of post-COVID-19 economies.

This paper addresses a forward-looking perspective on how COVID-19 disease can serve as a positive factor for short-term and long-term changes in energy production by PV systems around the world.

Maximum power point tracking of photovoltaic systems

Photovoltaic (PV) power is known as a popular resource among the various sources of renewable energy, which is well accepted due to some benefits such as free access, the presence of sunlight in most areas, the absence of rotating sections, the adaptation to the roofs of residential houses, and the low cost of repair and maintenance [10]. The power output of a photovoltaic system depends largely on its exposure to sunlight and solar panel temperature, and the power-voltage curve (P-V) has a unique MPP [14]. Receiving MPP from photovoltaic systems is considered as an important and fundamental factor in increasing the efficiency of these systems. As mentioned earlier, MPP refers to the single operating point of each solar cell. When the system is at this point, it has the highest benefit in power generation and the highest output power. However, these systems rarely work at MPP due to the changes that occur to the PV output characteristics under various factors such as radiation changes, temperature, and load size. Radiation change has more effect on the current than the voltage. Therefore, as the radiation decreases, it decreases the current more than voltage, leading to reduced power. Furthermore, the reduction of power has a greater effect on the voltage; thus, the voltage drops more than current when the temperature increases, resulting in reduced power [1]. However, a large initial investment is required for a photovoltaic power generation system; therefore, it is vital for the maximum radiation energy which the maximum radiation energy is extracted from. As a result, as the environmental conditions change, the MPP of a photovoltaic system changes, requiring a new search of MPP. Therefore, the maximum power point tracking (MPPT) becomes necessary.

The partial shading conditions in MPPT

Large photovoltaic systems usually consist of series-parallel arrays of photovoltaic modules, each consisting of a chain of series-connected photovoltaic cells. In such photovoltaic systems, some module components may receive less light from the sun due to the movement of clouds, tree shade, buildings, and other adjacent objects and air pollution. This phenomenon is called partial shading conditions. The bypass diodes are used in photovoltaic modules to prevent hot spots during such conditions. The voltage across each module in the series connection and the flow of chains are different under partial shading conditions and parallel connection, respectively, leading to multiple steps in the resulting I-V characteristics of the photovoltaic system. This effect is the presence of multiple peaks or multiple points of peak power in P-V characteristics. The P-V characteristics of photovoltaic systems become more complicated with bypass diodes under partial shading conditions in multi-peak mode. The highest point is called general MPP among these multiple peaks. Other points are called local peaks. The location and amplitude of the maximum local and general power points depend on the random changes to the shading pattern and the composition of the photovoltaic arrays. Common MPPT techniques, which assume only one peak power point on a typical photovoltaic curve, are unable to ensure convergence to the maximum global power point; and these methods are often trapped in one of the local peaks due to their instability in distinguishing between local and public peaks. To solve this problem, there is a need for developing powerful optimization algorithms which can achieve the maximum general power point in a photovoltaic system under partial shading conditions. Note that solar cells have several maximum characteristics when they are under partial shading conditions [19].

Global and diffuse irradiance

Solar irradiance can be measured in the space or on the surface of the earth after passing through the atmosphere. The amount of solar irradiance depends on the distance from the sun and the sun cycle. Solar irradiance reaching the earth (Rs) is one of the important parameters in energy balance and plant growth models and real evapotranspiration and plant potential models. Rs can be the result of two processes. In the first process, the irradiance reaches the upper surface of the atmosphere (Ra) before entering the earth’s atmosphere. In the second process, the irradiance passes through the atmosphere and finally reaches the earth’s surface. In general, the irradiance reaching the earth’s surface in clear, cloudless weather is about 57% of Ra and is virtually 52% of Ra in fully cloudy weather [21].

It is possible to identify nitrogen dioxide (NO2), one of the major pollution contaminants triggering smog and acid rain in urban regions, as well as ozone formation in the atmosphere [16]. Further, parameters such as NO2 can change the irradiance level [13]. NO2 that deteriorates respiratory problems is produced by power plants, vehicles, and other industrial facilities and can affect human health. The concentration of NO2 in the earth’s atmosphere varies extensively on a daily basis due to the emission oscillations and the changes in weather conditions [13].

The methodology

The equivalent circuit of a PV cell can be presented by a current source in parallel with a diode. A parallel resistor (Rp) is connected to the equivalent circuit of the PV to limit the leakage current. Similarly, a series resistor (Rs) is used to measure the loss. There are generally two types of modeling: (a) single-diode modeling, and (b) two-diode modeling. The latter one is more accurate. However, this requires more parameters to model the PV cell; hence, the authors adopt the single-diode model for its simplicity [7].

The single-diode model needs five parameters. The equation of PV cell’s output is expressed using the Kirchhoff’s current law (KCL):

\[
I_{pv} = I_{phs} - I_o \left( \exp \left( \frac{V_{oc}}{V_{oc}a} \right) - 1 \right) - \frac{V_{pv} + I_{pv}R_s}{R_p} \tag{1}
\]

\[
I_o \left( \exp \left( \frac{V_{oc}}{V_{oc}a} \right) - 1 \right) = I_0 \text{ shows the current equation of the diode and } I_0 \text{ represents the inverse saturation current. } R_s \text{ and } R_p \text{ are series and parallel resistors, } a \text{ is the ideal coefficient of the diode, and } V_{oc} \text{ is the thermal voltage at any temperature. The output equation of a PV module consists of several series and parallel cells:}
\]

\[
I_{pv} = \sum_{i=1}^{n_s} \sum_{j=1}^{n_p} \left[ I_{phs} - I_o \left( \exp \left( \frac{V_{pv}}{V_{oc}a} \right) - 1 \right) - \frac{V_{pv} + I_{pv}R_s}{R_p} \right] \tag{2}
\]

\[
N_{SS} \text{ and } N_{PP} \text{ give the number of cells with series and parallel connections [7].}
\]

Current and voltage equations to find the change of irradiance/ partial shading conditions (PSC) are written as follows:
\[ V_{PV}(k) - V_{PV}(k-1) \geq 0.2 \]  (3)

\[ I_{PV}(k) - I_{PV}(k-1) \geq 0.1 \]  (4)

\( k \) corresponds to the number of iterations, \( V_{PV} \) and \( I_{PV} \) are voltage and current of the PV. In continuous experiments, constants 0.2 and 0.1 for voltage and current are obtained by trial and error [7].

Results

The study area and solar irradiance data

The images displayed in Fig. 1 show that concomitant lockdown measures to prevent the spread of coronavirus have significantly reduced the level of \( NO_2 \) concentrations across Europe. Recent data from the Copernicus Sentinel-5P satellite show that some cities have seen a 45 to 50\% reduction compared to the same period in the previous year. The main objective of the Copernicus Sentinel-5P mission is to perform atmospheric measurements with high spatio-temporal resolution, to be used for air quality, ozone and UV radiation, and climate monitoring and forecasting (2020a) [15].

Scientists at the Royal Dutch Meteorological Institute (KNMI) have monitored air pollution in Europe in recent months using Tropomi constructive data from the Copernicus Sentinel-5P satellite (2020b) [2]. As lockdown measures continue in the coming weeks, the KNMI team will continue to analyze other countries more closely in Northern Europe, where more changes will be seen in the data due to the varying weather conditions. Features of the Copernicus Sentinel-5P satellite include high resolution and accurate ability to track gases, as well as unique measurements of \( NO_2 \) concentrations.

Fig. 1 shows new images of \( NO_2 \) concentrations from March 13 to April 13, 2020 compared to March and April 2019, and coincidentally with the strict quarantine measures taken across Europe, cities such as Madrid, Milan, and Rome experienced a 45\% drop on average, while Paris recorded a significant 54\% drop (2020c) [3]. Fig. 2 shows the average concentration of \( NO_2 \) in India from January 1 to March 24, 2020, and from March 25 (the first day of lockdown) until April 20, 2020.

The concentration of \( NO_2 \) is one of the important indicators of air pollution [6]. The \( NO_2 \) particles in the air deflect the sun’s rays toward the earth and can reduce the energy produced by the solar panels. Diffuse radiation (kWh/m\(^2\)) is shown in orange, while global radiation (9 kWh/m\(^2\)) is shown in yellow. Fig. 3-(a) shows that diffuse radiation is 46.82 kWh/m\(^2\) in March 2019 and 51.02 kWh/m\(^2\) in March 2020 after the lockdown. Fig. 3-(b) shows that the diffuse radiation in March 2019 is 54.31 kWh/m\(^2\) and in March 2020 is 68.21 kWh/m\(^2\), while Fig. 3-(c) shows that the diffuse radiation in March 2019 is 37.62 kWh/m\(^2\) and in March 2020 is 49.04 kWh/m\(^2\). Fig. 3-(d) shows that diffuse radiation is 49.22 kWh/m\(^2\) in March 2019 and 52.14 kWh/m\(^2\) in March 2020.

By comparing the amounts of irradiance in 2019 and 2020 among the mentioned countries, we can see the benefits of the presence of coronavirus to the growth of energy produced by the PV systems. Simultaneously with the spread of the virus, the lockdown law has been implemented in most countries in Asia and Europe and has inadvertently helped reduce air pollution by reducing the concentration of \( NO_2 \) gas. Therefore, the implementation of PV systems during the post-COVID-19 dilemma will provide significant solutions. By ramping up clean energy technology and generating many new opportunities for the unemployed, industries can be revived. Employment in the renewable and sustainable energy industries, which went through 11 million jobs worldwide in 2018, would grow by 2050 to more than 84 million jobs in all renewable energy fields (2019).
Fig. 3. The amount of irradiance curve in (a) France, (b) Italy, (c) Spain, and (d) India in 2019–2020.
consequently, as the temperature increases, the voltage decreases more and after COVID-19; an increased power generation is observed by traffic law. Fig. 4 (a) shows the amount of power generated before to quarantine, leading to reduced air pollution by involuntary non-

entirely shaded. The effect of the radiation change on the current is increased air pollution, radiation changes, temperature, load size, and characteristics of PV systems under various factors such as reduced and increased air pollution, when not-in-use vehicles reduced the NO$_2$ production and could play an important role in reducing air pollution. Then, this decrease in pollution led to increasing the energy generated by solar panels, indicating that the countries that had an investment in COVID-19 are faced with increased uncertainty risk and energy security. On the other hand, if countries that have invested in solar systems can use COVID-19 as an opportunity to benefit from more clean energy production, this will enhance their energy security.

The analysis reveals that there is an important association between possible behavior, change in air quality and increased production of electricity by photovoltaic systems. New data gathered from the Copernicus Sentinel-5P satellite reveals that certain cities have observed a 45 to 50 percent drop in the concentration of NO$_2$ relative to the same time last year. This decline has produced two major and unforeseen advantages, namely a reduction in environmental emissions, in particular air pollution, and, as a consequence, a rise in PV power production.

Conclusions
Along with the severe quarantine efforts made almost throughout the world due to the spread of the coronavirus, the Copernicus Sentinel-5P satellite recently mapped air pollution in Europe and Asia, showing a significant drop in NO$_2$ concentrations. The new images clearly show a sharp drop in the concentration of NO$_2$ in major European and Asian countries such as France, Italy, Spain, and India. This reduction has led to the maximum amount of irradiance reaching the earth’s surface, which has significantly increased the production capacity of solar panels. Thus, quarantine of cities and lockdown measures due to this disease have cause a reduction in the air pollution, hence somehow improving the environment.

That is why countries that were leading the way in the solar energy industry before the pandemic of COVID-19 have benefited from this increase in energy. Future perspectives based on the gained experience from the impact of COVID-19 on the solar energy industry can focus on solar energy efficiency measures; they should address these challenges less as technology optimization and more as institutional skills test and political commitment. However, COVID-19 could turn the environmental challenges into an opportunity with all its threats. Traffic restrictions and quarantine laws played an important role in reducing air pollution, when not-in-use vehicles reduced the NO$_2$ production and could play an important role in reducing air pollution. Then, this decrease in pollution led to increasing the energy generated by solar panels, indicating that the countries that had an investment in COVID-19 are faced with increased uncertainty risk and energy security. On the other hand, if countries that have invested in solar systems can use COVID-19 as an opportunity to benefit from more clean energy production, this will enhance their energy security.

CRediT authorship contribution statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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