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Research Article – Solar Energy

Simulating the Performance of Solar Panels in Iraq

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Abstract

The solar energy is the most available, non-polluting and free source of energy. Solar photovoltaic energy is the fastest growing energy resource and it will someday become the dominant source of energy. Iraq is located 290N-370N latitude so, it has a good possibility of solar energy, which could be invested to generate the electrical power by the photovoltaic modules .The used databases in this study are hourly data of irradiance were obtained from Photovoltaic Geographical Information System (PVGIS) while air temperature and wind speed were obtained from the European Centre for Medium-Range Weather (ECMWF) for the period 1/1/2001-31/12/2012. Mathematical MATLAB program has been created to estimate the cell temperature and electrical power of a monocrystalline module for 200 sites in Iraqi areas. This study states the effects of environmental parameters on both the cell temperature and the electrical power of a monocrystalline PV module. Irradiance on tilt surface, ambient temperature, and wind speed are the key environmental factors in this study. By using Arc GIS, maps of electrical power and cell temperature distributions of a monocrystalline were drawn based on NOCT model.It has found that the effect of solar radiation on the output electrical power from the PV module is greater than the effect of ambient air temperature. Also, it has found that the monthly electrical power received from the module is varied throughout the months for the study area where the highest electrical power was recorded in June and the lowest electrical power recorded in December. Also, it varies in different sites, the southern part of Al- Qadisyah, western part of Dhi-Qar, northern part of Al-Muthannia and southwestern part of Al-Anbar provinces recorded the highest values of electrical power while the lowest value in the eastern part of Dihok.

Keywords: photovoltaic, solar radiation, cell temperature, simulation.

Introduction

Energy is an important requirement in the life because it is an industrial and technological aspect. As a result, society faces the challenge of getting this continuous demand for sufficient energy and also plan for future energy supplies. Since the 1970s of the twentieth century, the world is witnessing a great increase in the demand for various energy sources because of the vast growth in the industry, but some of these sources are known for their depletion, high cost, and the negative impact of their use on the environment. The risk and fact of environmental degeneration during the last two decades have become more obvious, as the human activities have grown significantly. This is due to the increase in population of the world, energy consumption, and industrial activity (Kalogirou, 2009).

In this regard, renewable energy resources are one of the most efficient and active solutions (Kalogirou, 2009). Energy from the sun is the main energy resource and it supports all life on earth (Hameed, 2017). It is the most promising, alternative, sustainable, free, abundant, and non-polluting energy resource. The amount of solar energy striking the atmosphere of the earth constantly is 1.75×105 TW (T=tera=1012), considering a 60% transmittance through the cloud cover of the atmosphere, 1.05×105 TW reaches the earth's surface continually (Kalogirou, 2009). It is motivating to compare the global annual solar energy reaching the earth's surface with a global reserve of various fossil fuel (Chen, 2011). The reserve of fossil fuel is approximately 1.4 % of annual surface solar energy (Chen, 2011). If the irradiance only of 1% of earth's surface could be converted into electricity with 10% efficiency, it would supply 105 TW, while the global energy needs for the 2050 year are expected to be about 25-30 TW (Kalogirou, 2009). The full reserve of fossil energy will be exhausted in about 100 years, while the solar energy is a sustainable energy (Chen, 2011). The solar power from photovoltaic (PV) represents one of the promising renewable energy. The photovoltaic effect is defined as the physical process in which a photovoltaic cell converts visible light from sunlight into electricity (Kalogirou, 2009).

One of the most important parameters to estimate the long-term performance of PV module systems and their annual output electrical energy is the temperature of PV cells. The temperature of PV cell depends on many parameters such as the properties of manufacturing materials used in PV module covering, types of the PV cells and climatic conditions of the location. Exemplary, the efficiency of PV module substantially depends on its cells operating temperature. Increasing operating cell temperatures generally, decline the performance of the PV module to generate electricity (Piyatida et al., 2009). The output power from PV modules generally is estimated by a mathematical model based on the irradiance on the tilted surface, the ambient temperature, wind speed, and the manufacturer's data for the PV modules (Al-Khazzar and Al-Najjar, 2016). Especially, the basic solar radiation data for the surfaces of certain location are not easily available in most developing countries. Generally, the meteorological stations measure solar radiation data (global and diffuse solar radiation intensities) mostly on horizontal surfaces only, while the stationary solar photovoltaic cells are inclined towards the sun to achieve the maximum amount of irradiance incident on the cell surface. Thus, the irradiance on the tilt surface in most situations is determined by measured global horizontal irradiance (Hameed, 2017).

Bhattacharya *et al.* (2014) they studied the effects of weather factors such as ambient temperature and wind speed on the performance of a monocrystalline module. They elucidated that the results show a strong negative linear correlation between out power from the module and ambient temperature and a positive linear correlation between output power and wind speed.

Al-Khazzar and Al-Najjar (2016) simulated a hybrid (PV/wind) 2.7MW system for three selected cities in Iraq, pointed out that the hybrid system could give the required load for the months from March to September in the cities of Baghdad and Al-Muthanna. While larger system size is needed in Kirkuk

Abd Al-whaed and Abdulateef (2016) studied the effect of weather conditions such as solar radiation, ambient temperature, wind speed and humidity on the performance of the different photovoltaic solar modules by using MATLAB/Simulink in Baghdad. He simulated the efficiency and output power of monocrystalline module, polycrystalline module, amorphous module, and CIGS module. He showed that the output power of photovoltaic modules increases with decreasing cell temperature.

In this paper, mathematical MATLAB program has been created to estimate the cell temperature and electrical power of a monocrystalline module for 200 sites in Iraqi areas. This study states the effects of environmental parameters on both the cell temperature and the electrical power of a monocrystalline PV module. Irradiance on tilt surface, ambient temperature, and wind speed are the key environmental factors in this study. By using Arc GIS, maps of electrical power and cell temperature distributions of a monocrystalline were drawn based on NOCT model.

The Effect of Weather Variables on Performance of PV Solar Module

Many of weather variables effect on performance of PV modules such as solar radiation, ambient temperature, and local wind speed (Abd Al-whaed and Abdulateef, 2016).

The solar radiation has a significant effect on the performance of PV module due to its variant behavior from time to time. The variation of solar radiation with time can give different electricity power from the same PV module (Piyatida et al., 2009). A number of radiation components are needed for the design, sizing, performance, and research of different PV modules. These components include beam, diffuse, and total solar radiation [4/chapter 2]. Ambient temperature plays a major role on the performance of PV solar module because the change in temperature will affect the output of electrical power from the modules (Abd Al-whaed and Abdulateef, 2016). The performance of PV solar module decreases with increasing temperature because of the fact that the voltage is strongly dependent on the temperature and an increase in temperature will reduce the voltage as shown in figure 1 (Dubey et al., 2013; Mahdi, 2018). Consequently, an increase the temperature will decrease the efficiency and output power from a PV solar module (Abd Al-whaed and Abdulateef, 2016).

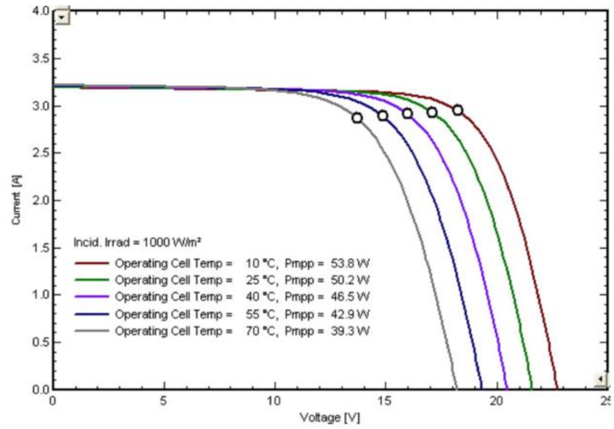

Fig. 1: Output Power from the PV Module with Different Temperatures (Fesharaki *et al.*, 2011).

Wind speed affects PV solar module performance through it is effect on the temperature and voltage of PV solar module. In other words, higher wind speeds decrease the air temperature as well the module operating temperature. This means that wind speed can help the solar system by reducing the operating temperature of the solar module and achieving higher efficiency (Abd Al-whaed and Abdulateef, 2016).

The Effect of Cell/Module Temperature

The cell/module daytime temperature is not simply equal ambient temperature, because the solar PV module has a dark color and absorb more solar energy from the sun. The performance of the PV solar cell directly depends on the cell temperature (Kalogirou, 2009). During the day, the operating solar cell temperature, is higher than the ambient temperature, as the cell temperature increases the voltage power, and efficiency of the PV module decreases. The measure of the cell temperature is complex, since many affecting parameters such as ambient temperature, solar radiation, wind speed, the absorption, heat dissipation, and the properties of manufacturing material of PV module (Kalogirou, 2009). There are many correlations to measure the cell temperature dependence on the electrical efficiency of PV module, although large of them assume usual linear form, differing only in the numerical values of parameters which depend on material and system of the solar PV module. The PV cell temperature rises over the ambient temperature and it is extremely sensitive to wind speed less than the wind direction. The electrical power is mainly influenced by the type of PV solar module that will be used (Dubey *et al.*, 2013).

The cell temperature can be determined by an energy balance, take into consideration that the absorbed solar radiation that is not converted to electrical power is converted to heat which is lost by dissipation to environment (Kalogirou, 2009; Al-Khazzar and Al-Najjar, 2016). If this heat dissipation is not possible, the heat should be removed by some mechanical methods, such as the air circulation, or by water heat exchange with the back side of PV; these systems are known as hybrid photovoltaic/thermal (PV/T) (Kalogirou, 2009). At high irradiance temperature reduction by using PV/T system of about 20 oC, which leads to a 9-

12% increase in electrical power, depending on stratification (Dubey *et al.,* 2013).

The energy balance on a PV module unit area that is cooled by heat lost by dissipation to environment is given as the follows:

$$(\tau\alpha)G_T = \eta_e G_T + U_L(T_C - T_a) \qquad (1)$$

Where (τα): the transmissivity - absorptivity product of the solar PV module cover, a value of 0.9 can be used without serious error, ηe is the PV module efficiency, UL is the universal heat transfer coefficient (losses by radiation and convection from the front and back of PV solar module to environment, Ta is the ambient air temperature (oC) (Kalogirou, 2009; Al-Khazzar and Al-Najjar, 2016).

By applying the load at the nominal operating cell temperature (NOCT) conditions, which defined as the temperature of a PV solar module at the conditions of 800 W/m2 irradiation (GT,NOCT), 20ºC ambient temperature (Ta,NOCT), and 1 m/s average wind speed with no load (ηe = 0) the eq. equation (2-20) becomes (Kalogirou, 2009):

$$(\tau\alpha)G_{T,NOCT} = U_L\left(T_{NOCT} - T_{a,NOCT}\right) \qquad (2)$$

Which can be rearranged to determine the ratio:

$$\frac{(\tau\alpha)}{U_L} = \frac{\left(T_{NOCT} - T_{a,NOCT}\right)}{G_{T,NOCT}} \qquad (3)$$

By offset equation (3) into equation (2) and implementing the necessary manipulation, the following equation can be obtained (Kalogirou, 2009):

$$T_C = T_{a+}\left(T_{NOTC} - T_{a,NOTC}\right)\left[\frac{G_T}{G_{T,NOTC}}\right]\left[1 - \frac{\eta_e}{(\tau\alpha)}\right] \qquad (4)$$

It should be noted that the above equation can be applied only when the module efficiency is given, if it wasn't given, then a trial-and-error solution needs to be applied. In this procedure, an empirical formula that can be used for estimation of PV module temperature of polycrystalline solar cells was obtained by Lasnier and Angas (1990) as a function of the solar radiation (GT), and the ambient temperature (Ta), is given by (Kalogirou, 2009):

$$T_C = 30 + 0.0175(G_T - 300) + 1.14(T_a - 25) \qquad 5)$$

After few simplifications, equation (1) also can be given in the following form to predict the cell temperature (Al-Khazzar and Al-Najjar, 2016:

$$T_C = T_{a+}\left(T_{NOTC} - T_{a,NOTC}\right)\left[\frac{G_T}{G_{T,NOTC}}\right]\left[1 - \frac{\eta_e}{(\tau\alpha)}\right]\left(\frac{U_{L,NOTC}}{U_L}\right) \qquad (6)$$

Since the term (ηe/τα) is a small term compared to other terms, it could be neglected. Also, the heat loss term between the PV solar module and the ambient air is replaced by using Nusselt‑Jurgess correlation. Thus, the equation (6) can be written as the following diminutive form where the cell temperature can be determined at any weather condition such as ambient temperature, solar radiation and wind speed (Al-Khazzar and Al-Najjar, 2016):

$$T_C = T_{a+}\left(T_{NOTC} - T_{a,NOTC}\right)(1 - \eta_r)\left(\frac{G_T}{800}\right)\left(\frac{9.5}{5.7 + 3.8 \times W}\right) \qquad (7)$$

Where ηr is the module efficiency at Standard Test Conditions (STC) [1000W/m2 solar radiation, and 25 oC cell temperature]. Efficiency is an important measurement of PV cell that is commonly reported. It is defined as the maximum electrical power output (Pmax) divided by incident light power (Pin). It is given as follows (Kalogirou, 2009):

$$\eta_{max} = \frac{P_{max}}{P_{in}} = \frac{maximum\ current \times maimum\ voltage}{AG_T} \qquad (8)$$

Where A is the area of the solar module.

The PV module efficiency at actual condition can be estimated according to the cell temperature as fallows (Dubey *et al.,* 2013).:

$$\eta_e = \eta_r[1 - \beta_r(T_c - T_r) + \gamma \log_{10} G_T] \qquad (9)$$

Where Tr is the cell temperature at STC (Tr=25), βr is the temperature coefficient of PV module efficiency and equals to 0.0041 oC-1or K-1 for monocrystalline silicon cell, γ is the solar radiation coefficient having the value of 0.12 for monocrystalline silicon cell which is usually taken as a zero and the equation becomes (Dubey *et al.,* 2013).

$$\eta_e = \eta_r[1 - \beta_r(T_c - T_r)] \qquad (10)$$

The typical quantities of ηr and βr are given by the sheet of PV module manufacturing. Generally, they can be obtined from the flash tests where the electrical power from the PV module is measured at two different temperatures for a given irradiation. Particularly, the actual value of the temperature coefficient depends on the PV material and Tr. It is given by the ratio:

$$\beta_r = \frac{1}{T_o - T_r} \qquad (11)$$

Where To is the maximum cell temperature at which the PV module efficiency drops to zero. It has a value of 270 oC for crystalline silicon PV module ((Fesharaki *et al.,* 2011; Dubey *et al.,* 2013).

The electrical power (Ppv) that could be delivered by the area of PV panel/array (A) is given as follows (Al-Khazzar and Al-Najjar, 2016):

$$P_{pv} = A\eta_e G_T \qquad (12)$$

By substituting equation (10) with equation (12), the following equation can be obtained (Al-Khazzar and Al-Najjar, 2016)

$$P_{pv} = A\eta_r G_T[1 - \beta_r(T_c - T_r)] \qquad (13)$$

Results and Discussion:

In this work, there are two types of using data that were taken for 200 sites to cover all areas of Iraq as shown in the figure (2). The first one represents solar radiation on a tilted plane obtained from the PVGIS site (ECSKC). The data consists of one year of monthly mean hourly incident solar radiation, this year represents an average year for the period of 2001- 2012. The second type represents data of air temperature and wind speed obtained from the ECMWF site (PVGIS). This data consists of air temperature on 2 m height, and u and v wind speed components on 10 m height. The second type consists of hourly data of 12 years with 3 hours' time step.

Cell/Module Temperbature

By using equation (7), cell temperature was estimated as shown in the table (1). By using Arc GIS program, figures 3

Table 1. Monthly Mean Hourly Cell Temperature at 12 PM o'clock.

Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dihok	19.8	22.5	27.7	32.6	39.9	49.5	55.0	54.0	47.4	40.6	33.5	23.8
Ninwa	25.8	29.2	34.1	38.1	45.2	53.2	59.2	58.6	51.9	46.6	39.0	29.0
Arbil	27.1	30.7	34.6	38.9	45.8	53.3	59.0	59.0	52.2	47.0	40.3	30.7
Kirkuk	26.8	29.9	33.9	39.0	45.7	52.0	56.6	57.3	51.8	46.4	39.4	30.7
Sualymaniyah	20.0	22.1	26.8	32.7	39.9	48.8	53.7	54.3	47.8	40.0	33.2	24.7
Slaa al-Din	30.7	35.0	39.4	44.6	49.7	52.7	55.4	57.0	53.9	51.0	40.4	33.1
Dyaila	31.2	35.8	40.4	45.8	51.0	53.4	56.0	57.7	54.4	51.2	40.8	33.2
Anbar	30.9	36.0	41.3	47.8	51.9	52.7	54.6	56.9	55.0	52.5	39.5	32.5
Baghdad	32.0	36.9	41.8	47.6	52.1	53.6	55.9	57.8	54.9	52.4	41.3	34.0
Karbala	32.1	37.0	42.7	49.7	53.6	53.6	55.3	58.0	56.5	53.9	40.2	33.3
Babil	33.4	38.2	43.7	50.2	53.8	53.9	56.0	58.4	56.4	55.0	41.7	34.7
Waset	33.1	37.6	42.5	47.2	50.7	52.5	54.8	56.9	52.7	49.9	40.7	34.1
Najaf	32.9	37.8	43.8	50.8	54.2	54.0	55.9	58.4	56.7	54.9	41.0	34.2
Qadisyah	33.3	37.9	44.1	50.6	53.8	53.8	55.8	58.1	55.7	54.5	41.1	34.2
Maysan	34.0	39.3	43.8	49.0	51.8	53.7	56.3	58.8	54.3	51.1	42.4	35.0
Muthannia	35.3	40.6	46.9	52.1	55.8	54.6	56.2	58.9	56.8	57.2	43.5	37.1
Dhi-Qar	33.4	38.5	44.0	50.3	53.5	53.2	55.3	57.8	54.5	53.2	40.9	33.9
Basra	33.6	40.0	46.3	51.1	54.6	54.5	57.0	60.4	55.5	52.6	41.4	34.1

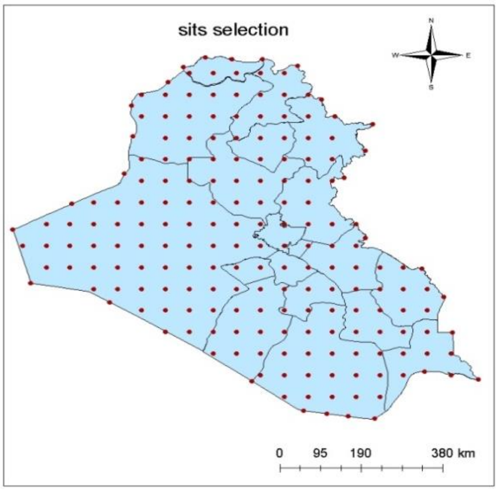

Fig. 2 Site Selection in Iraqi Areas.

was drawn based on the equation (7) showing the monthly mean hourly cell temperature (°C) on 2 m height at 12 PM o'clock for June and December months, respectively.

Electrical Power Received by a PV Module

It necessary to estimate the amount of electrical power received from a PV module when designing and simulating the performance of PV module. The annual mean hourly ($\overline{P_{pv}}$) and annual mean daily ($\overline{E_{pv}}$) electrical power that could be received by a monocrystalline module for 18 chosen sites that are the closest to the province's center in Iraqi areas are shown in the table (2). By using Arc GIS program figure (3) was drawn showing the annual mean daily electrical power (KWh) that could be received from a monocrystalline module for 200 site of Iraqi area.

This value can be multiplied by 365 to get the annual electrical power (KWh). As we see from the above figure, the annual mean hourly electrical power from a monocrystalline ranges from (1.27-1.66) KWh, where the highest value was recorded in the southern part of Al- Qadisyah, western part of Dhi-Qar, northern part of Al-Muthannia and southwestern part of Al-Anbar provinces, while the lowest value in the eastern part of Dihok.

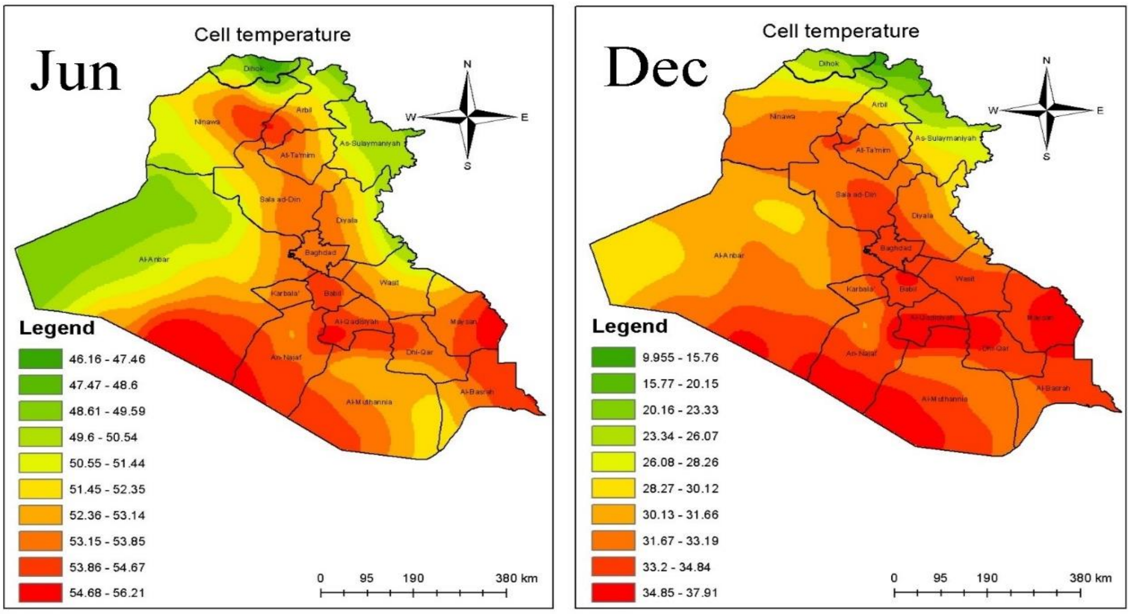

Fig. 3 Monthly Mean Hourly Cell Temperature at 2 m Height at 12 PM o'clock.

Table 2. Annual Mean Hourly and Daily Electrical Power from the Monocrystalline Module.

Area	$\overline{P_{pv}}$ (Wh)	$\overline{E_{pv}}$ (KWh)	Area	$\overline{P_{pv}}$ (Wh)	$\overline{E_{pv}}$ (KWh)
Dihok	184.82	1.428	Karbala	185.73	1.411
Ninwa	185.26	1.432	Babil	194.15	1.472
Arbil	183.71	1.421	Waset	187.73	1.432
Kirkuk	185.97	1.433	Najaf	191.00	1.440
Sualymaniyah	189.14	1.462	Qadisyah	193.63	1.458
Slaa al-Din	191.61	1.471	Maysan	185.28	1.411
Dyaila	189.17	1.446	Muthannia	218.60	1.641
Anbar	184.93	1.422	Dhi-Qar	190.39	1.440
Baghdad	189.94	1.454	Basra	186.53	1.416

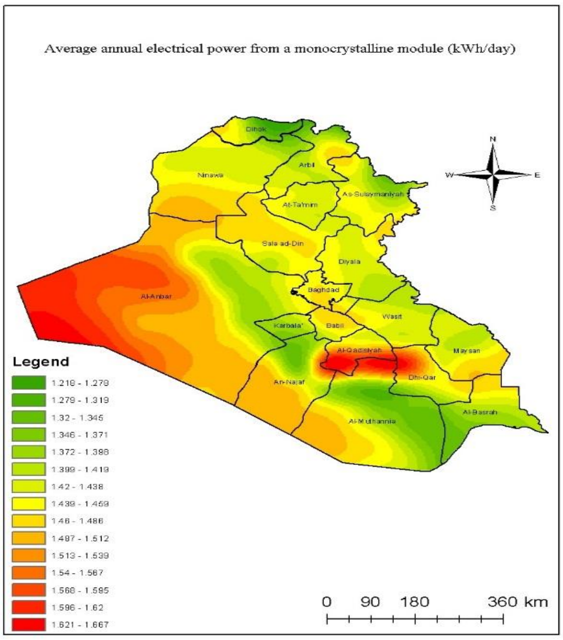

Fig. 4 Annual Mean Daily Electrical Power from a Monocrystalline Module (KWh/day).

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