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Numerical analysis of photovoltaic power generation in different locations of Bangladesh

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Abstract

Photovoltaic (PV) module is one of the most useful, sustainable and non-harmful products in the field of renewable energy. It offers longer service period for least maintenance cost. The elements of PV are abrasive, easy for designing, and their structure like the stand-alone technique gives production from micro to mega-power level. A 3D numerical system of PV module has been built up and solved applying FEM technique-based software COMSOL Multiphysics in this article. The average solar irradiation and optimum tilt angle for six divisions (Dhaka, Chittagong, Rajshahi, Khulna, Barishal and Sylhet) in Bangladesh have been calculated. The effects of solar radiation, angle of inclination, ambient temperature, and partial shading on temperature of solar cell, electrical power and PV module's electrical efficiency have been investigated. It has been observed from the results that the greatest value of electrical power 15.14 W is found in Rajshahi for solar radiation 209 W/m^2. The highest electrical efficiency is found as 12.85% in Sylhet at irradiation level of 189 W/m^2. For every 1° increase of inclination angle, electrical power and electrical efficiency level devalue by 0.06 W and 0.05%, respectively. Results also show that the efficiency level decreases from 14.66 to 11.32% due to partial shading area from 0 to 40%. PV module's electrical power; and electrical efficiency reduces approximately 0.01 W and 0.01%, respectively due to every 1°C addition of solar cell temperature.

1. Introduction

Solar energy is collected from normal procedures that are refilled continuously. Hosenuzzaman et al. [1] described that solar energy can be found in various forms; and may be collected straightly from the sun or else from heat generation inside the earth. Heat and electricity can be produced from renewable properties like sun, wind, hydro-power, biomass, ocean, geothermal resources, biofuels, hydrogen, etc. [2, 3]. Renewable energy is mostly created from the sun either indirectly or directly. Sunlight (solar energy) may be utilized straightly for heating buildings, lighting homes, producing electricity, water heating, and various types of industrial and commercial usages [4-6]. Power for each unit area on the Earth's region is called sunlight's irradiation. sunshine is the electromagnetic radiative part given off by the sun, mainly able to be seen, infrared, and ultraviolet daylight. In the world, sunshine is sifted throughout the Earth's ambiance and clear as light of the day while the sun is on the top of the horizontal axis. If the clouds cannot block the direct irradiation, then it is assumed as sunshine, an arrangement of radiant heat and clear light. Solar PV module will produce the greatest one in terms of output and capacity. PV technology will report for as much as 7% of worldwide power production by 2030 [7-14].

The PV module's inclination angle is one of the controlling factors of best possible energy yield. Solar panels or PV arrays work with highest efficiency if they are set as perpendicular to the direction of the sun's rays. Optimal inclination angle of solar PV is dissimilar at different location of the world. The highest incident irradiation is significant for power production which may be obtained with the optimization of sun tracking technique [15-17]. To remove dust from PV surface and enhance PV efficiency, forced convective air conditioning system has been used by Ali et al. [18]. Chedid et al. [19] used numerical simulation for finding the performance of PV arrays of different operating conditions.

Partial shading is another important parameter to affect PV power generation adversely. Partial shading effects of disparity loss for the difference in solar radiation level all the way through the system. It can happen to yearly performance decreases of 10–20% or further in housing installations. It is a common observable fact that happens when some solar cells inside a module array are covered by passing clouds, buildings, birds, or various other things. Shading of the photovoltaic cells may result in considerable energy drop of photovoltaic technologies. Shading of objects like buildings, clouds, birds, and trees on photovoltaic arrays decreases the sunshine that the arrays obtain, inevitably consequential in lesser system efficiency. In a photovoltaic array, two different types of shading (partial) may happen. The first type is static partial shading, where a particular darkness continues on the photovoltaic array of a time. The second one of shading is dynamic partial shading, where shadows are in motion over the photovoltaic array for the swaying brushwood of trees or the moving clouds. The effect of dynamic partial shading is brutal on huge scale photovoltaic arrays. Shading of photovoltaic arrays, either partial or total, can have a noteworthy impact on their energy yield and power generation, depending on photovoltaic arrays configuration, bypass diodes integrated in photovoltaic modules and shading pattern. Shadows falling on photovoltaic arrays will decrease the overall power generation in two ways: a) by dropping the power input to the solar cell, and b) by escalating energy fatalities in the partially shaded solar cells [20-26].

From the above literature, it is apparent that photovoltaic technology is one of the best ways out to attain sustainable and clean energy goal if the efficiency and power density may be progressed more. However, there is a very inadequate research (numerical and experimental) based on photovoltaic module in Bangladesh. The aspires of the current research are to examine the tilt angle, solar radiation, ambient temperature and partial shading effects on PV performance under different operating conditions in Bangladesh. Considering photovoltaic mechanism of solar cell improves the electrical performance of a photovoltaic module. This is due to the fact that sunlight comes from sun and passes through the top glass layer of PV module, and strikes the solar cell; then the electrical power is generated, and the direct current is obtained. This direct current can be changed into the alternative current.

2. Methodology

The SY-90M m-Si PV module has been considered for the present numerical research (Rahman et al. [12] and Mamun et al. [19]). The PV module has a total of 36 cells, each with dimensions of 125×125 mm^2. The total dimensions of the module are 1200×545×35 mm^3, and its maximum output power is 90 W. Usually, a photovoltaic module has five layers: bottom polyvinyl fluoride (PVF), ethylene vinyl acetate (EVA), mono-crystalline silicon solar cell, EVA, and top glass cover. These five layers are established in a metallic frame. The standard conditions of the module are recorded in Table 1.

The thickness, density, specific heat capacity, and thermal conductivity of each layer of PV have been shown in Table 2. The properties of the PV panel materials are assumed to be independent of the temperature. The prevailing wind conditions and varying ambient temperatures also have significant effects on the thermal response time of the PV panel.

2.1. Schematic diagram

The schematic diagram of the PV module has been shown in Fig. 1. The solar cells (mono-crystalline) with traditional EVA coating on both sides and PVF (tedlar) lamination on the bottom side, and glass cover on the top side have been arranged. All these layers of PV are ingrained in aluminium metallic frame.

2.2. Physical properties of PV

The materials properties of the PV module have been displayed in Table 3 according to Nasrin et al. [11], Rahman et al. [15] and Mamun et al. [22].

2.3. Mathematical technique

The expression of the total gained energy by the cell of the PV module:

$$E_{in} = \tau_g \alpha_{sc} G A \tag{1}$$

By the natural convection process, few parts of the above received energy goes to outside of PV module through glass:

$$E_l = U_{sca} \left(T_{sc} - T_a \right) A \tag{2}$$

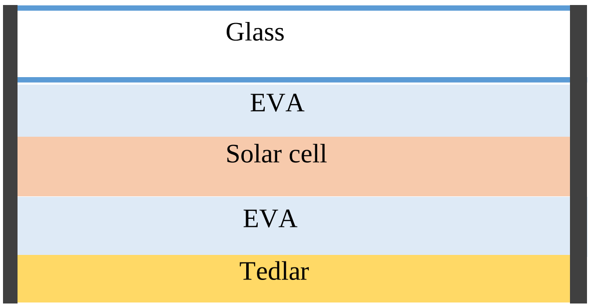


Fig. 1. Schematic drawing of photovoltaic module.

Table 1. Specification of photovoltaic module.

Material	Material mono-crystalline silicon (m-Si)
Original place	China (Mainland), Hebei
Name of brand	SHAIYANG
Number of model	SY-90M
Number of cells	4×9
Size (mm)	1200×545×35
Maximum power (W)	90
Isc (A)	5.30
Voc (V)	22.03
Imp (A)	4.90
Vmp (V)	18.36
Size of cell (mm)	125×125
Weight (kg)	7.0

Table 2. Properties of photovoltaic layers.

Layers	Thickness (m)	Density ρ (kg/m^3)	Specific heat capacity C_p(J/kgK)	Thermal conductivity k (W/mK)
Tedlar	1.1×10-4	1200	1250	0.20
EVA	500×10-6	960	2090	0.35
Solar cell	225×10-6	2330	677	148
Glass	3.1×10-3	3000	500	1.80

Table 3. The properties of Photovoltaic module.

Properties	Value
Transmissivity of glass, τ_g	0.96
Glass emissivity, ε_g	0.04
Absorptivity of solar cell, α_{sc}	0.9
Absorptivity of tedlar, α_{td}	0.95
Coefficient of heat transfer from glass to ambient, U_{ga} (Wm^{-2}K^{-1})	7.14
Heat transfer coefficient inside PV surfaces, U_{sc} (Wm^{-2}K^{-1})	94
Coefficient of heat loss from bottom surafce to ambient, U_{tda} (Wm^{-2}K^{-1})	6
Solar cell's reference efficiency, η_{sc} (%)	0.15
Solar cell efficiency's thermal coefficient, μ_{sc} (%/°C)	-0.00045
Temperature of reference, T_r (°C)	25
Solar cell number	4*9
Each solar cell area (mm^2)	125*125
Ambient temperature, T_a (°C)	27

From the rest energy some amount of electrical power is produced:

$$E_e = \eta_{sc} GA \tag{3}$$

The rest of the energy is converted as thermal energy:

$$E_t = U_{sctd}\left(T_{sc} - T_{td}\right)A \tag{4}$$

Thus, the equation of energy conservation for a photovoltaic module is:

$$E_{in} = E_l + E_t + E_e \tag{5}$$

Using Eqs. (1-5), the solar cell temperature is:

$$T_{sc} = \frac{G\left(\tau_g \alpha_{sc} - \eta_{sc}\right) + (U_{sca} T_a + U_{sctd} T_{td})}{\left(U_{sca} + U_{sctd}\right)} \tag{6}$$

The three dimensional numerical model has been conducted in steady state formulation. EVA's transmitivity has been assumed as 100%; no dirt on photovoltaic surface can influence the absorption of solar energy. The leading PDE's of thermal energy for photovoltaic's solid layers have been written below:

For the glass

$$-\left(\frac{k}{\rho c_P}\right)_g \left(\frac{\partial^2 T_g}{\partial x^2} + \frac{\partial^2 T_g}{\partial y^2} + \frac{\partial^2 T_g}{\partial z^2}\right) = \alpha_g G - U_{ga}\left(T_g - T_a\right) - \varepsilon_g \sigma\left(T_g^4 - T_s^4\right) - U_{gsc}\left(T_g - T_{sc}\right) \tag{7}$$

For the cell

$$-\left(\frac{k}{\rho c_P}\right)_{sc} \left(\frac{\partial^2 T_{sc}}{\partial x^2} + \frac{\partial^2 T_{sc}}{\partial y^2} + \frac{\partial^2 T_{sc}}{\partial z^2}\right) = \alpha_{sc}\tau_g G - E_e - U_{sctd}\left(T_{sc} - T_{td}\right) - U_{gsc}\left(T_{sc} - T_g\right) \tag{8}$$

For the tedlar

$$-\left(\frac{k}{\rho c_P}\right)_{td} \left(\frac{\partial^2 T_{td}}{\partial x^2} + \frac{\partial^2 T_{td}}{\partial y^2} + \frac{\partial^2 T_{td}}{\partial z^2}\right) = U_{sctd}\left(T_{sc} - T_{td}\right) - U_{tda}\left(T_{td} - T_a\right) \tag{9}$$

where σ = 5.670367 × 10-8 $Wm^{-2}k^{-4}$ is the constant of Stefen-Boltzmann.

2.3.1. PV's boundary conditions

At the bottom of photovoltaic:
natural convection of heat transfer = $U_{tda}\left(T_{td} - T_a\right)$;

At the PV's side boundaries: no heat transfer (insulation) $\frac{\partial T}{\partial n} = 0$;

Here *n* is the perpendicular distances along x or y or z directions to the boundary.

2.3.2. PV's electrical power

The PV's electrical power (output) may be calculated as:

$$E_p = \eta_{sc}\tau_g \alpha_{sc} GA\left[1 - \mu_{sc}\left(T_{sc} - T_r\right)\right] \tag{10}$$

2.3.3. Electrical efficiency

The instant electrical efficiency of photovoltaic is:

$$\eta_e = \frac{\text{Generated electrical power}}{\text{Total gained energy}} = \frac{E_p}{E_{in}}$$

2.4. Numerical procedure

For computational technique and graphical depiction, the software COMSOL Multiphysics and Microsoft Excel, respectively have been employed in this numerical research. The Galerkin FEM of [27-28] has been applied to solve the leading PDE along with proper boundary conditions for the present numerical problem. Conservation equations of energy has been resolved using FEM to get the temperature of the PV layers. The temperature (*T*) of governing Eqs. (7-9) has been elaborated with basis set. The Galerkin FEM gives the residual equations in nonlinear form. The technique of Gaussian quadrature has been applied to get the integrals of equations. The residual equations (nonlinear) have been solved by Newton–Raphson technique to evaluate the expansion coefficients. The solutions convergency has been considered as $\left|\phi^{n+1} - \phi^n\right| \le 1e^{-6}$, where ϕ is function of temperature (T) and n is iteration number.

2.4.1. Test of grid refinement

A wide grid refinement technique has been performed to assure grid-independent resolution for Ta = 27°C, G = 200 W/m^2 through a PV module. In this research, a non-uniform grid technique of four types hasbeen inspected with the elements number: 12, 870; 23, 929; 55, 230 and 1,68,454. Table 4 shows the test results. It may be observed from the fourth and fifth column that there is no major modification in the solar cell average temperature's value but computation time intolerable. Thus, allowing 55,230 elements of grid system (non-uniform) is preferable for the present computation.

2.4.2. Generation of mesh

The discrete locations at which the variables are to be calculated are defined by a mesh which covers the geometric domain on which the problem is to be solved. It divides the solution domain into a finite number of sub-domains called finite elements. Fig. 2 displays the finite element mesh of the present physical domain. The meshing consists of tetrahedral element with ten nodes in subdomain and triangular element with six nodes in boundaries.

2.4.3. Validation of the model

The numerical result has been validated for cell temperature at solar radiation 1000 W/m^2, 0% partial shading, tilt angle of 0° and ambient temperature 18°C for the photovoltaic module with that of Mamun et al. [22]. They [22] experimentally (indoor) studied the effects of partial shading and tilt angle of photovoltaic module in Malaysia. The influences of irradiation, cell temperature, partial shading and tilt angle were studied in [22]. PV module (SY-90M) of mono-crystalline cells was used in their indoor experiment. The range of operating temperature of that experiment was (-40 - 75°C). The validation has been depicted in Table 5. Percentages of errors between these two types of results have been also shown in this table. Numerical results produced by using the present numerical code concurs well with that of Mamun et al. [22]. Thus, this numerical technique may generate convincing results to investigate the photovoltaic performance.

3. Results and discussion

The functioning of a PV module is intrinsically dynamic. The unlike behavior of wind and irradiation are transitory in the environment. Hence, a dynamic simulation is a predominant requirement for forecasting operating temperatures of the photovoltaic module when the radiation is swiftly changeable. On the other hand, the variation between simulation results using the dynamic and steady-state models are insignificant for particular time of the day under certain sky conditions and the nature of the radiation. For getting a precise forecast of the PV module yield, it may be essential to produce the outcomes when steady-state situation is found. In present research, the 3D steady-state model has been used instead of the extra time-unbearable three dimensional dynamic model.

Table 4. Grid check with T_a = 27°C and G = 200 W/m^2.

Meshing type	Coarser	Coarse	Normal	Fine
Elements	12,870	23,929	55,230	1,68,454
Cell temperature (°C)	52.4035	52.9124	53.7429	53.7431
Time (s)	98	153	265	387

Table 5. Validation of numerical model against the experimental result.

Parameter	Mamun *et al.* [22]	Present research
Cell temperature	53.19°C	51.31°C
Electrical power	54.84 W	57.24 W
Electrical efficiency	10.01%	10.67%

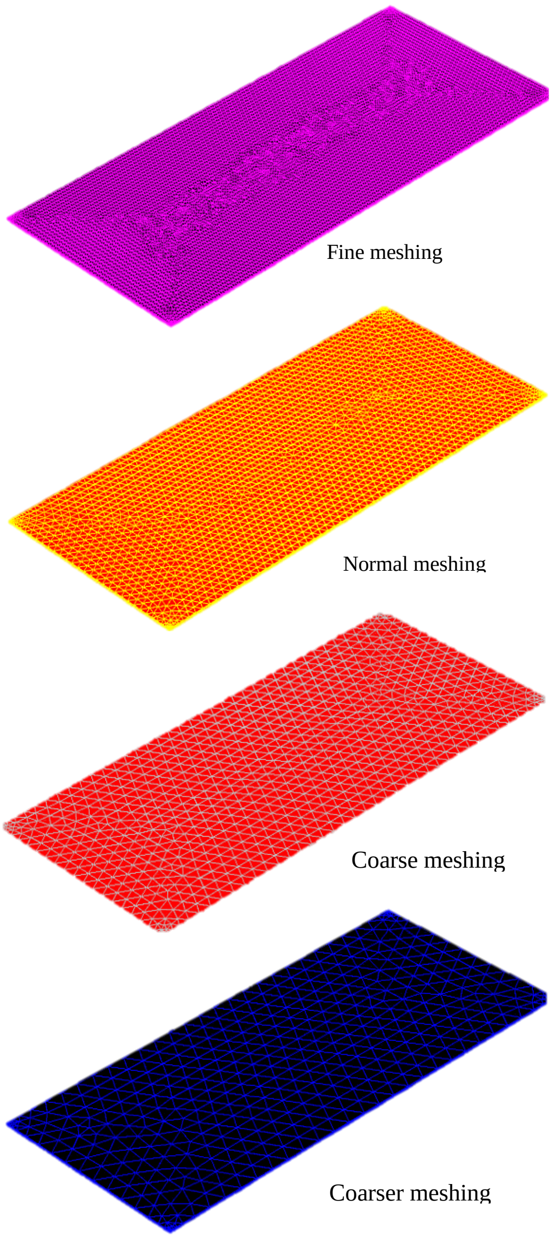


Fig. 2. Different types of meshing of module.

3.1. Irradiation level in Bangladesh

Bangladesh is a state of huge sunlight; however, the accessibility to a power resource is not great, if the essential technology to tie energy together is not accessible. It is situated from $20^0 30^/$ to $26^0 45^/$ north latitude and its climate is tropical. Bangladesh is a fine receiver of sun energy due to its location. Its total area is 1.49E+11 m^2 and receives monthly average irradiation of 5 KWh/m^2 by this land per year. Throughout the last decades significant advances in various solar energy machineries have been done and already some have attained the commercial phase.

Monthly irradiation (KWh/m^2) at different positions of Bangladesh has been shown in Table 6 according to Nasrin [29]. The highest amount of solar radiation all over Bangladesh has been monitored in May and the smallest amount in December.

Thus, yearly average irradiation for Dhaka, Rajshahi, Sylhet, Chittagong, Barisal and Khulna has been calculated and found as 197, 209, 189, 192, 196 and 202 W/m^2 respectively. Yearly mean irradiation level in Bangladesh can be considered as 200 W/m^2.

3.2. Tilt angle in Bangladesh

The position of the sun may be normally specified on the celestial sphere in the form of solar altitude (α) and azimuth (ψ) angles. The angular distance of sun from the south and the horizon can be measured by the solar azimuth and altitude angles, respectively. In addition, the angular distance of sun from the zenith may be measured by solar zenith angle (φ). This is the point which overhead directly on the celestial sphere. So, α and φ and are the angles of the complementary. The inclination angle is the angle at which the surface is tilted from the horizon and is considered positive for surfaces of south facing. The calculation procedure of tilt angle is given in Nasrin [29] and Chowdhury et al. [30] in detail.

The solar azimuth and altitude angles can be calculated for any date, time, and position by the relation $\alpha = 90^0 - \varphi + \delta$, where δ and φ are the declination angle and the latitude considered north direction of the equator, respectively.

In other way the value of δ can be :

$$\delta = 23.45^0 \sin\left[\frac{360}{365}(284+d)\right],$$

where d denotes as number of the day in the year. If $\alpha + \beta = 90^0$, then the direction of the incident sunlight is perpendicular to the surface, where β and α are the tilt and elevation angles, respectively of the solar photovoltaic module calculated from the horizon.

Now, it can be clear that $\beta = \varphi - \delta$

In Bangladesh for Dhaka division, longitude and latitude are 90.41^{0}E and 23.7^{0}N, respectively. The inclination angles are

a) For 3rd October, 2018 (Autumn), d = 276.

Thus, δ = -5.007^0

Now $\beta = \varphi - \delta = 23.7^0 - (-5.007^0) = 28.707^0$

b) For 25th May, 2018 (Summer),

d = 31+28+31+30+25 =145.

So, δ = 20.916^0

Now $\beta = \varphi - \delta = 23.7° - 20.916° = 2.78°$

Similarly, the inclination angle of photovoltaic module in Dhaka capital city of Bangladesh is obtained using Microsoft excel software and the average value has been obtained as 23.8°. In this way, the remaining five tilt angles of the station have been obtained as 22.4, 22.8, 22.9, 24.5 and 24.9° for Chittagong, Barisal, Khulna, Rajshahi and Sylhet, respectively.

3.3. Effect of irradiation

The effect of irradiation on photovoltaic module in the form of surface temperature plot has been presented in Fig. 3. The considered values of solar irradiation are G = 189 W/m^2 (for Sylhet), 192 W/m^2 (for Chittagong), 196 W/m^2 (for Barisal), 197 W/m^2 (for Dhaka), 202 W/m^2 (for Khulna) and 209 W/m^2 (for Rajshahi) in Bangladesh. The surface temperature of the PV module in this six stations on average has been obtained approximately from 52.2 to 55.7°C. Since irradiation (G) is closely different,PV surface temperature becomes very close. The ambient temperature has been considered as 27°C. The range of surface temperature has been found for Sylhet region from 52.1 to 53°C, for Chittagong region from 52.5 to 53.4°C, for Barisal region from 53 to 53.9°C, for Dhaka region from 53.1 to 54.1°C, for Khulna region from 53.8 to 54.8°C, and for Rajshahi region from 54.7 to 55.7°C, respectively.

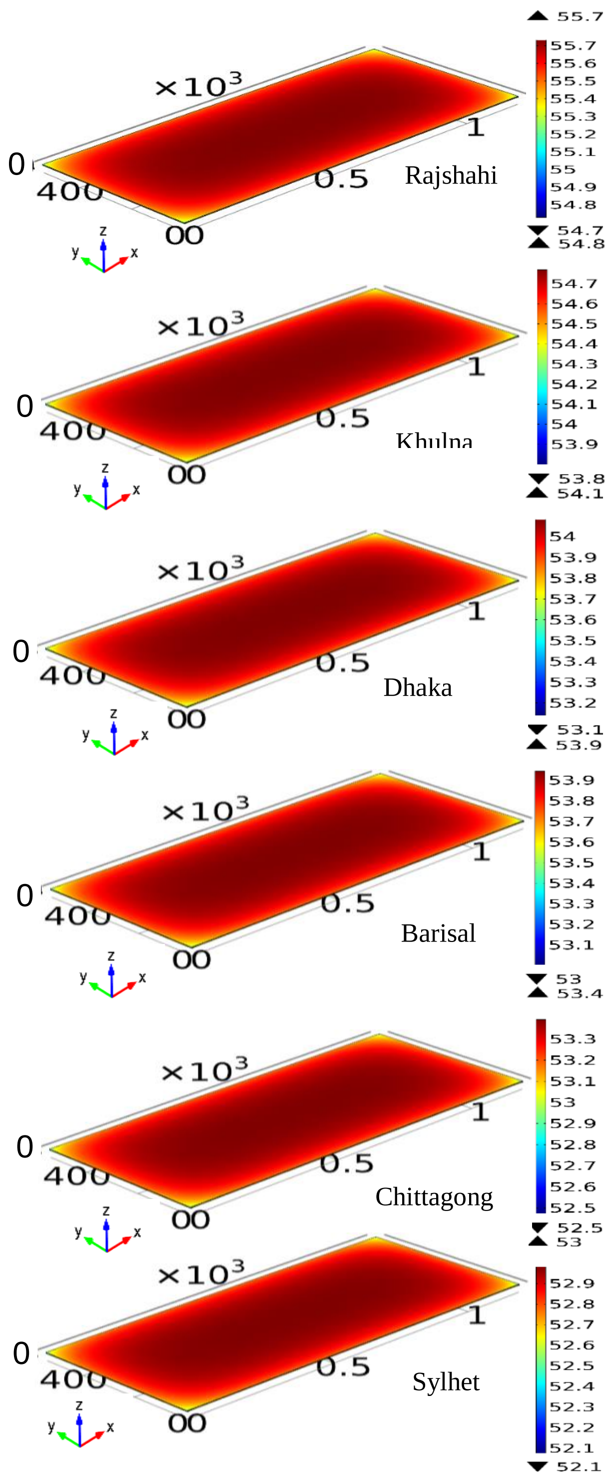


Fig. 3. Surface temperature of module against irradiation.

Fig. 4(a-c) shows the cell temperature, electrical power and electrical efficiency due to various irradiation level for six stations in Bangladesh. The PV solar cell mean temperature in Sylhet, Chittagong, Barisal, Dhaka, Khulna, Rajshahi divisions with respect to irradiation has been found as 52.66, 53.06, 53.6, 53.74, 54.42 and 55.3℃, respectively. As the irradiation level of six stations in Bangladesh is very close to each other, the solar cell average temperature obtained have very close values.

The electrical power (E_p) has been calculated by using Eq. 10. The electrical power of PV module in Sylhet, Chittagong, Barisal, Dhaka, Khulna, Rajshahi locations has been found as 13.71, 13.93, 14.21, 14.28, 14.64 and 15.14 W, respectively. From Fig. 4(b) it has been noticed that the range of electrical power in these six stations in Bangladesh has been recorded approximately from 13.71 to 15.14 W.

The electrical efficiency of PV module in Sylhet, Chittagong, Barisal, Dhaka, Khulna and Rajshahi divisions in Bangladesh with respect to irradiation has been obtained to be about 12.85, 12.84, 12.83, 12.82, 12.81 and 12.80%, respectively. It has been noticed from Fig. 4(c) that the electrical efficiency varies from 12.80 to 12.85%.

3.4. Effect of tilt angle

The considred tilt angles are 22.4, 22.8, 22.9, 23.8, 24.5 and 24.9° for Chittagong, Barisal, Khulna, Dhaka, Rajshahi and Sylhet, respectively. The irradiation level and ambient temperature have been assumed to be 200 W/m^2 and 27℃, respectively. Fig. 5 displays the surface temperature plot of PV module for different tilt angles of six stations in Bangladesh. The range of PV surface temperature in Chittagong, Barisal, Khulna, Dhaka, Rajshahi and Sylhet regions has been found to be from 52.5 to 53.4℃, from 53 to 53.9℃, from 53.8 to 54.8℃, from 53.1 to 54.1℃, from 54.7 to 55.7℃ and from 52.1 to 53℃, respectively. This variation of PV surface temperature occurs due to different tilt angles of these six locations in Bangladesh.

Three types of data (cell temperature, electrical power and electrical efficiency) are shown in Fig. 6(a-c) with respect to the tilt angle.

Table 6. Monthly solar radiation.

No. of month in year	Sylhet	Chittagong	Khulna	Rajshahi	Barisal	Dhaka
01	4	4.01	4.25	3.96	4.17	4.03
02	4.63	4.69	4.85	4.47	4.81	4.78
03	5.2	5.68	4.5	5.88	5.30	5.33
04	5.24	5.87	6.23	6.24	5.94	5.71
05	5.37	6.02	6.09	6.17	5.75	5.71
06	4.53	5.26	5.12	5.25	4.39	4.8
07	4.14	4.34	4.81	4.79	4.2	4.41
08	4.56	4.84	4.93	5.16	4.42	4.82
09	4.07	4.67	4.57	4.96	4.48	4.41
10	4.61	4.65	4.68	4.88	4.71	4.61
11	4.32	4.35	4.24	4.42	4.35	4.27
12	3.85	3.87	3.97	3.82	3.95	3.92
M (KWh/m^2/day)	4.54	4.56	4.85	5	4.71	4.73
Average (W/m^2)	189	192	202	209	196	197

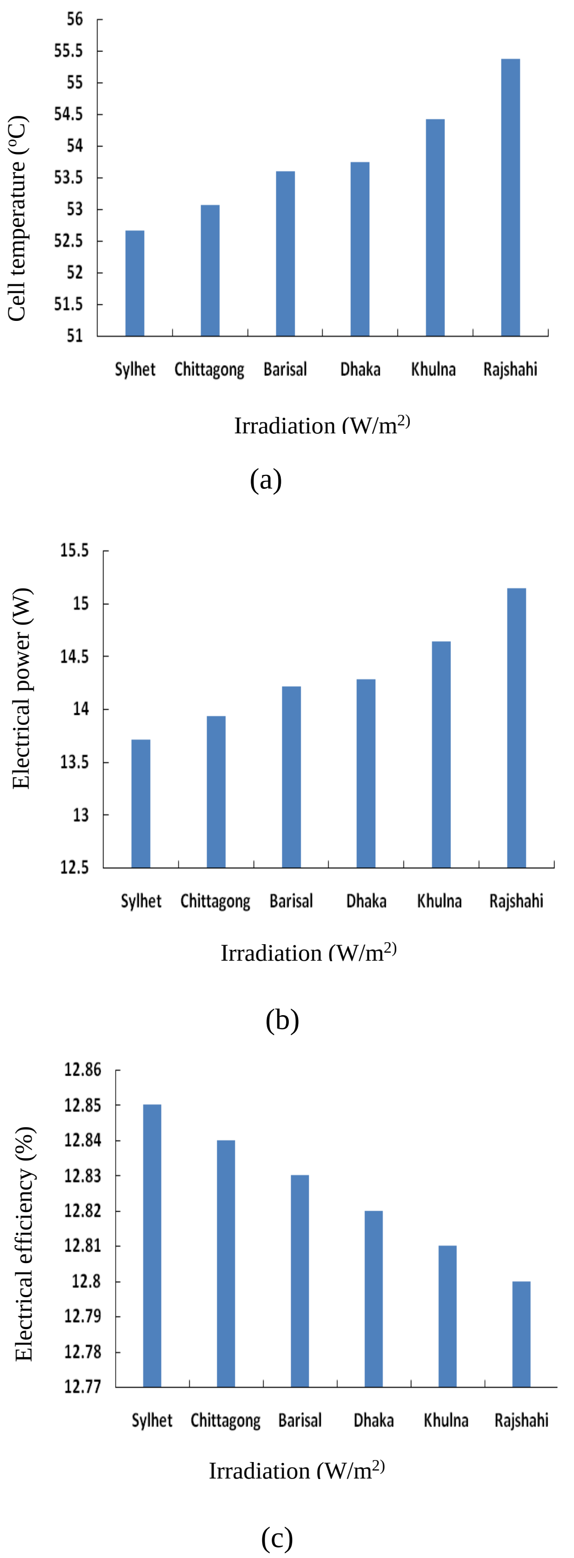


Fig. 4. Solar radiation effect on (a) photovoltaic cell temperature, (b) photovoltaic power and (c) efficiency.

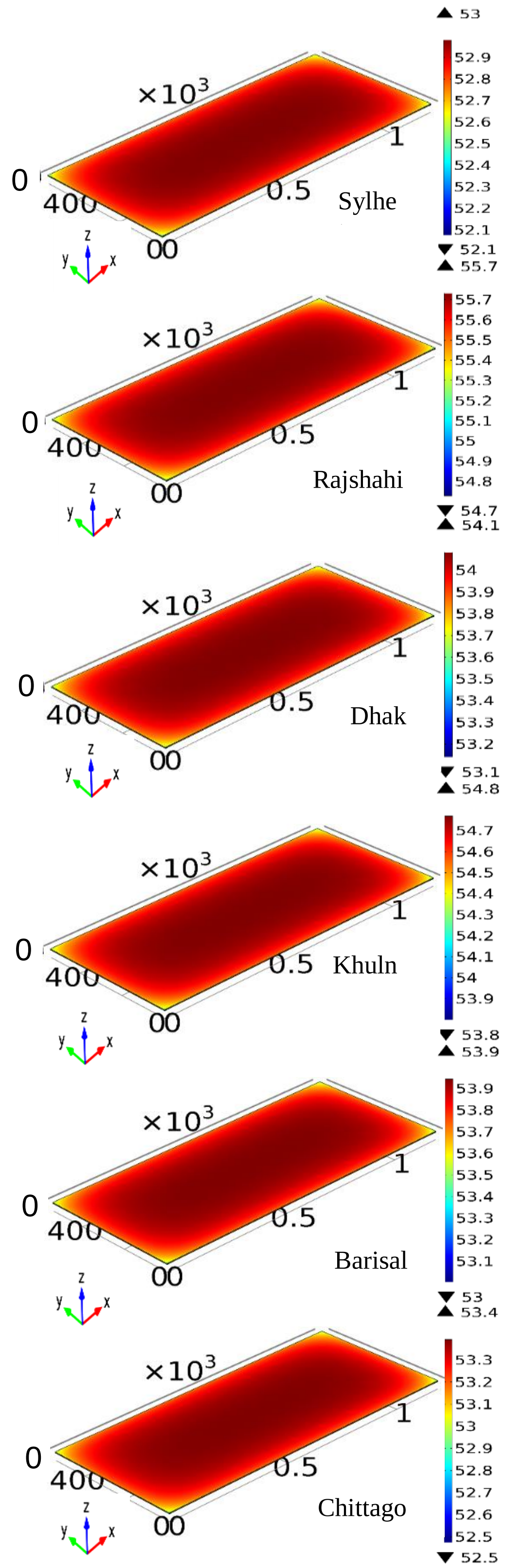
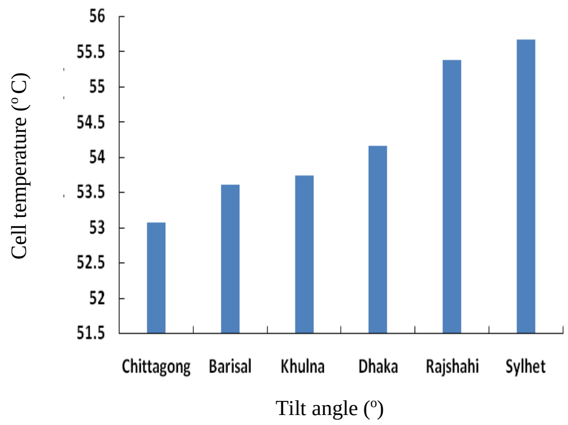
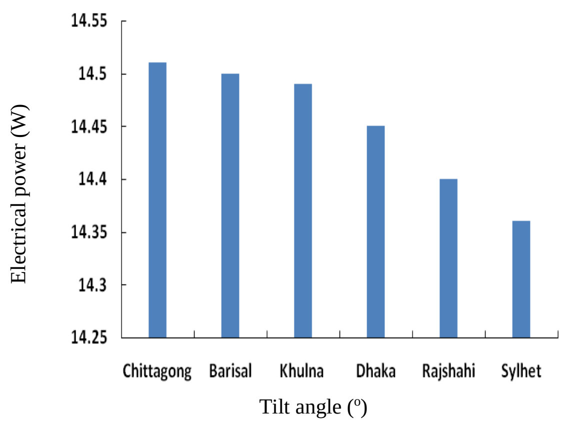


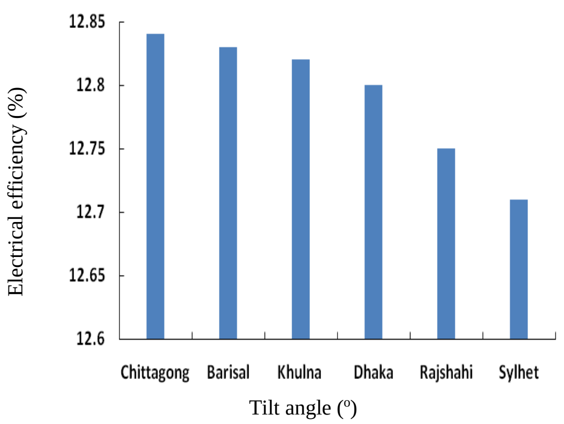
Fig. 5. Module's surface temperature against tilt.



(a)



(b)



(c)

Fig. 6. Tilt angle effect on (a) solar cell temperature, (b) electrical power and (c) efficiency.

The photovoltaic cell temperature has been obtained by applying Eq. 6. The cell temperature (T_{sc}) increases with the increase of tilt angle gradually. Since tilt angle and cell temperature increase simultaneously, the photovoltaic power and electrical efficiency reduce gradually.

The electrical power (E_p) of the PV module has been shown against the above tilt angles (for Chittagong, Barisal, Khulna, Dhaka, Rajshahi and Sylhet divisions) in Fig. 6(b). It has been noticed from this figure that about 14.51, 14.50, 14.49, 14.45, 14.40 and 14.36 W electrical power has been obtained if the PV module is located in Chittagong, Barisal, Khulna, Dhaka, Rajshahi and Sylhet division, respectively in Bangladesh.

The electrical efficiency (η) of the PV module against tilt angle has been calculated by using Eq. (11) and is displayed in Fig. 6(c). Approximately 12.84, 12.83, 12.82, 12.80, 12.75 and 12.71% of the PV electrical efficiency have been obtained in Chittagong, Barisal, Khulna, Dhaka, Rajshahi and Sylhet locations, respectively.

3.5. Ambient temperature effect

The ambient temperature effect on solar photovoltaic module has been shown in Fig. 7 in terms of surface temperature plot of PV. The ambient temperature (T_a) has been taken 10, 17, 27 and 37°C. This range of ambient temperature covers the whole six seasonal temperature range in Bangladesh. In this case, solar irradiation and tilt angle have been kept fixed as 200 W/m^2 and 0°, respectively. At the ambient temperature of 10°C, the PV module's surface temperature increases from 36.7 to 37.7°C. Similarly, at 17°C ambient temperature, PV surface temperature increases from 43.6 to 44.6°C, at 27°C ambient temperature, it increases from 53.6 to 54.5°C, at 37°C ambient temperature, it increases from 63.4 to 64.4°C.

Mean values of mono-crystalline solar cell temperature (T_{sc}), electrical power (E_p) and electrical efficiency (η) of the solar panel for the deviation of T_a have been depicted in Fig. 8(a-c).

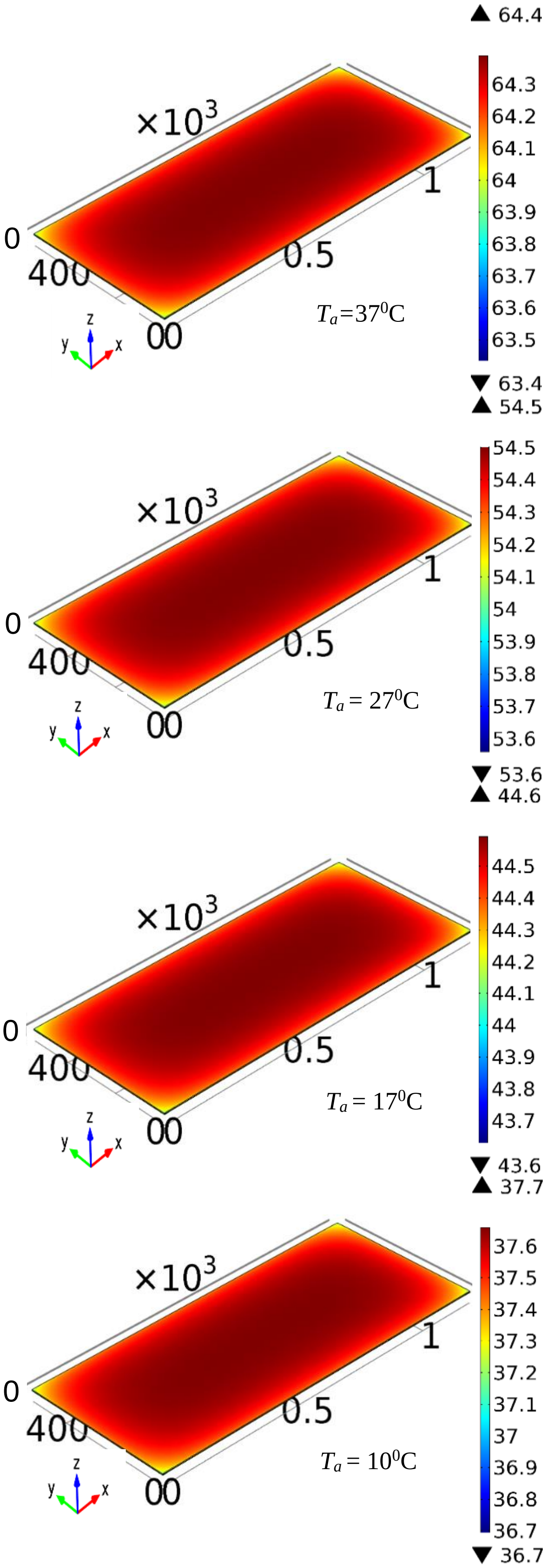


Fig. 7. Photovoltaic's surface temperature against ambient temperature.

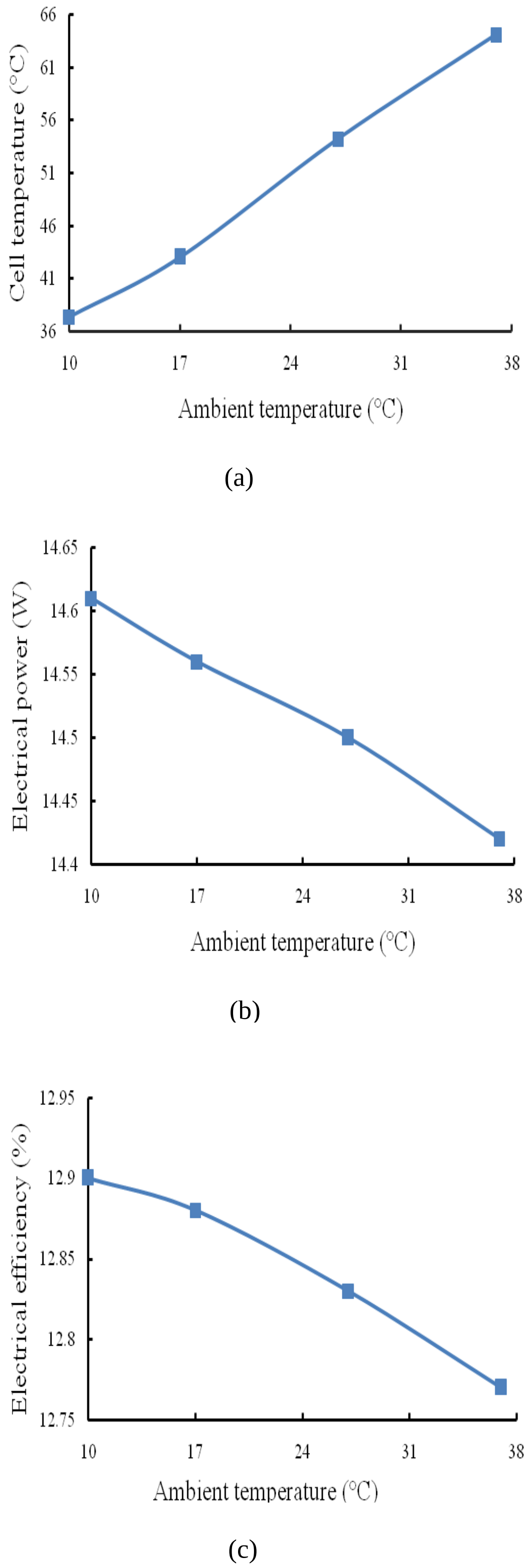


Fig. 8. Ambient temperature effect on (a) cell temperature, (b) power and (c) efficiency.

For increasing values of ambient temperature (10-37°C), convective heat transfer from photovoltaic module to the ambient air is reduced. So, fewer heat is taken out from PV module by natural convection which increases solar cell mean temperature by 37.32, 44.25, 54.15 and 64.05°C for ambient temperature 10, 17, 27 and 37°C respectively. Due to the increasing ambient fluid temperature, mean temperature of cell is increased at constant irradiation 200 W/m^2. As a result, photovoltaic current enhances slightly with considerable drop in photovoltaic voltage which, consecutively, devalues the electrical power and efficiency.

The power output (E_p) has been collected as 14.61, 14.56, 14.49 and 14.43 W respectively for increasing values of T_a from 10 to 37°C. The convective heat transfer phenomena fall with the rising ambient temperature. Thus, this decreasing tendency has been found in PV module's power generation.

The electrical efficiency (η) of PV module has been found by 12.93, 12.89, 12.83 and 12.77% for ambient temperature 10, 17, 27 and 37°C, respectively in Fig. 8(c). This decreasing trend occurs as rising values of ambient fluid temperature cannot absorb more heat from PV module and thus cell temperature rises.

3.6. Effect of partial shading

The partial shading effect on photovoltaic surface temperature with constant solar radiation 200 W/m^2, tilt angle 0° and ambient temperature 27°C has been illustrated in Fig. 9. The partial shading range has been considered from 0 to 40%. This figure shows that the partial shading affects photovoltaic's surface temperature noticeably. Increase percentage of shading area devalues PV's surface temperature. The PV's surface temperature range becomes from 53.2 to 54.1°C, from 37.3 to 54.2°C, from 30.4 to 54.5°C, from 28.1 to 54.2°C and from 27.3 to 54.5°C for 0, 10, 20, 30 and 40% partial shading respectively.

The average values of solar cell temperature, power generation and electrical efficiency for various partial shading has been expressed in Fig. 10(a-c), respectively.

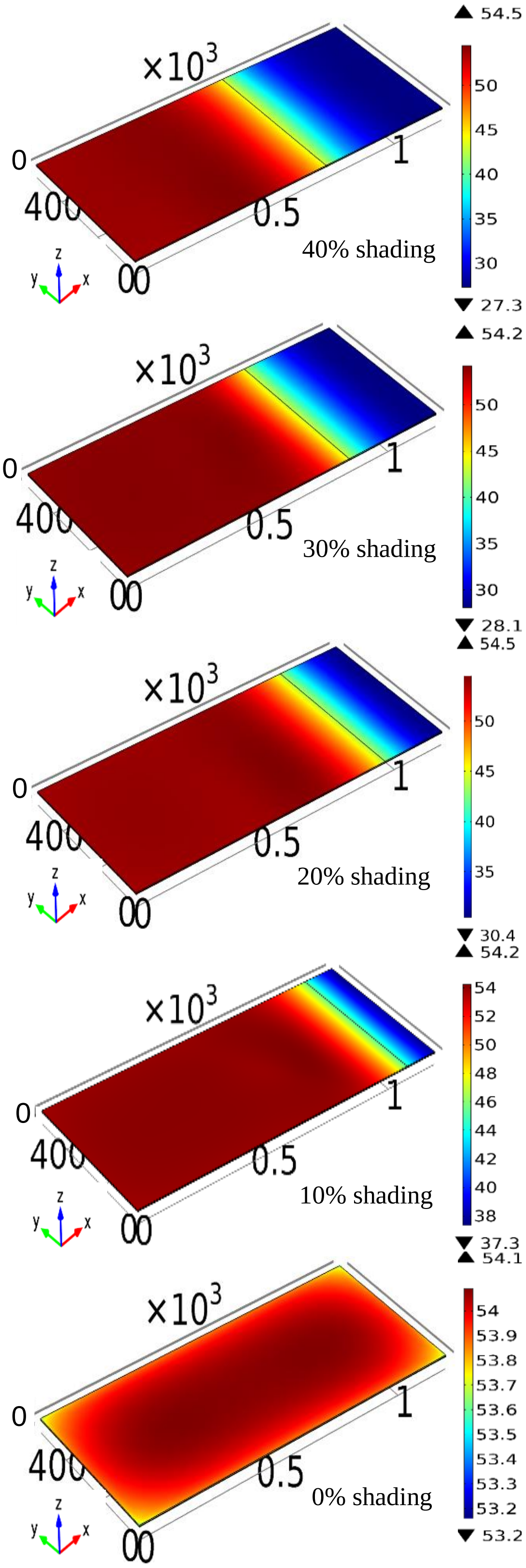
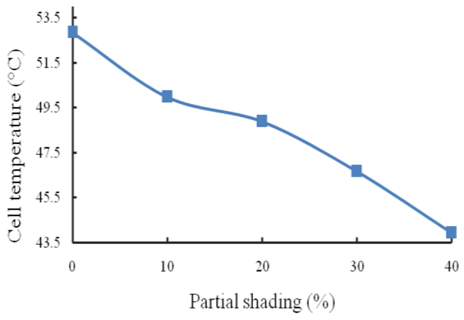
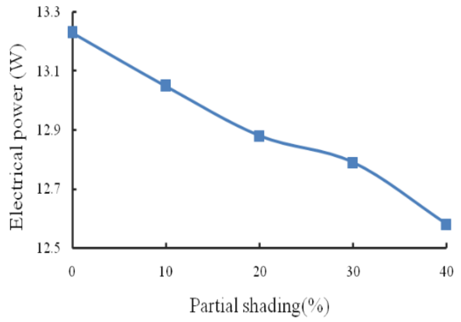


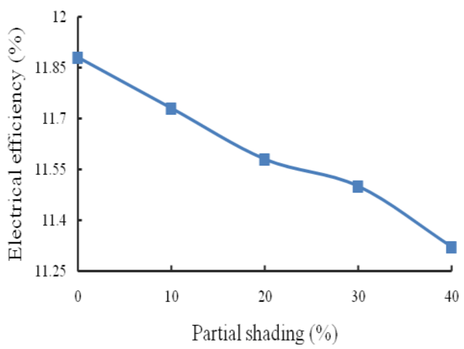
Fig. 9. Photovoltaic's surface temperature against partial shading.



(a)



(b)



(c)

Fig. 10. Partial shading effect on (a) photovoltaic cell temperature, (b) power generation and (c) efficiency.

It has been revealed from the Fig. 10(a) that for no shading condition, the photovoltaic's cell temperature is 54.09°C. This cell temperature decreases approximately 50.62, 49.36, 46.66 and 43.99°C for the increasing values of partial shading from 10 to 40%, respectively.

Power generation is negatively affected by partial shading and photovoltaic module's efficiency is conversely comparative to shading area. Fig. 10(b-c) shows that at 200 W/m^2 solar radiation and under 0% shading situations, the electrical power and PV's efficiency have been found as 16.33 W and 14.66%. At 10% shading, the electrical power and efficiency are fallen to 13.06 W and 11.73%, respectively. When the photovoltaic area has been shaded by 20%, the electrical power and efficiency go down again to 12.88 W and 11.58%, respectively. At the case of 30% shading area of PV top surface, the electrical power and photovoltaic's efficiency are fallen to 12.80 W and 11.50%, respectively. Finally, for 40% shading area, the electrical power and PV's efficiency decrease to 12.58 W and 11.32%, respectively.

Fig. 10(c) shows that the efficiency of the photovoltaic for no shading area is obtained more than that of 10-40%. Thus, the photovoltaic performance appreciably depends on the shading area.

3.7. Effect of cell temperature

The PV's power and efficiency are affected by the solar cell temperature. Fig. 11(a-b) expresses the phenomena for constant solar radiation level 200 W/m^2 and fixed ambient temperature 27°C. For increasing PV's cell temperature, electrical power and efficiency are decreasing gradually. Electrical power generation and efficiency of PV reduce for the increasing values of cell temperature with constant solar radiation. These results assure Eqs. (10 and 11).

In this study for the photovoltaic module at solar radiation 200 W/m^2, solar cell temperature, output power and efficiency have been found as 48°C, 15.27 W and 12.87%, respectively. After that, with fixed irradiation level, the electrical power about 15.25, 15.24, 15.23 and 15.21W and the electrical efficiency approximately 12.85, 12.84, 12.83 and 12.82% has been calculated for the increasing solar cell temperature 50, 52, 54 and 56°C, respectively.

Thus, increasing the temperature of solar cell up to 56°C devalues the output power and efficiency up to 15.21W and 12.82%. The power and efficiency of the photovoltaic decrease from 15.27 to 15.21 W and from 12.87 to 12.82%, respectively for escalating temperature of solar cell ranging from 48 to 56°C. At every 1°C addition of temperature of solar cell; power generation and PV's efficiency, lessen to 0.01 W and 0.01%, respectively.

Thus cell temperature is a very important parameter for PV module's power supply. A photovoltaic module will normally operate at 25°C with 1000 W/m^2. However, when operating in the outside, these are generally operated with higher temperatures and lower insulation situations. For obtaining PV's maximum power, it is necessary to investigate the probable operating temperature of the PV module.

3.8. Comparison

The present numerical result for a mono-crystalline solar photovoltaic has been compared with a few results of the experiments. Table 7 expresses the respective judgment of PV's efficiency lessening (%) with the augmentation of every 1°C solar cell temperature. The PV's efficiency diminution for each enhance of 1°C solar cell temperature result from various studies [31-33], and current result has been depicted in this table. Nahar et al. [31] found 0.13% decrement of the electrical efficiency at every augment of cell temperature 1°C. Alternatively, [32 and 33] observed falling tendency of PV's efficiency by 0.03 and 0.05%, respectively for every 1°C addition of solar cell temperature. The present numerical simulated result concurs absolutely with Bahaidarah et al. [32].

A small difference is noticed with [31 and 33] due to dissimilar operating situations. Thus, with the intention of getting higher power generation and PV's efficiency, the temperature of solar cell cannot be enhanced following a convinced level. Cell temperature is contrariwise connected to the electrical efficiency of the photovoltaic.

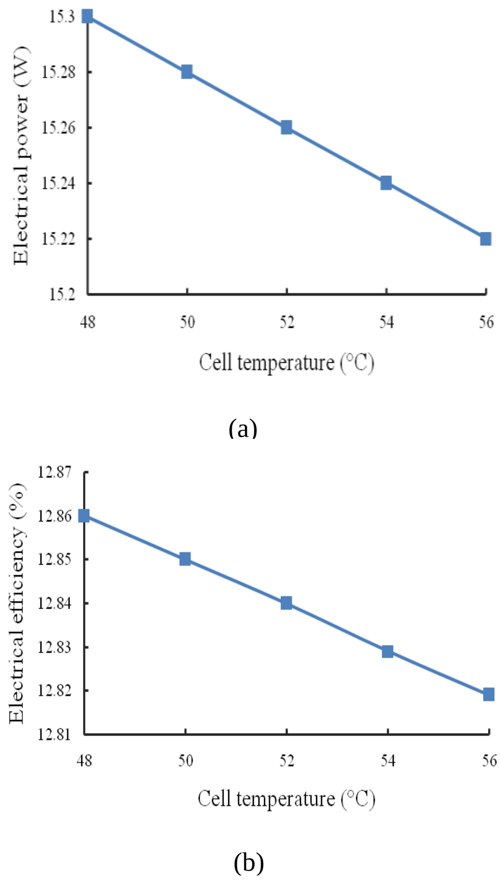


Fig. 11. Cell temperature effect on (a) electrical power and (b) efficiency.

Table 7. Reduction of efficiency with increasing cell temperature.

Name of research	Irradiation (W/m^2)		Cell temperature (°C)		T_a (°C)	Electrical efficiency		Efficiency lessening (%) per 1°C addition (cell temperature)
	Initial	Final	Initial	Final		Initial	Final	
Nahar *et al.* [31]	1000	1000	60.5	66	34	10	9.3	0.13
Bahaidarah *et al.* [32]	240	979	25	44	21	15.7	15.2	0.03
Chandrasekar *et al.* [33]	600	1300	37	65	37	10.3	9	0.05
Present work	200	200	48	56	27	12.87	12.82	0.01

4 Conclusions

The current three-dimensional numerical simulation of PV module has a large function in electrical power in Bangladesh. The overall conclusions can be written as follows:

- The mean temperature of cell, PV electrical power and efficiency vary from 52.66 to 55.3℃, from 13.71 to 15.14 W and from 12.80 to 12.85% in six stations in Bangladesh due to various irradiation level.
- The electrical power of the PV module has been found as 14.51, 14.50, 14.49, 14.45, 14.45, 14.36 W at Chittagong, Barisal, Khulna, Dhaka, Rajshahi and Sylhet, respectively for various inclination angle situations. The efficiency of the module is as 12.84, 12.83, 12.82, 12.80, 12.75 and 12.71 % under the same conditions.
- At every 1°C addition of ambient temperature PV's cell temperature increases 0.99°C, power generation and efficiency reduce to 0.007 W and 0.006%, respectively.
- Temperature of cell, PV's power and efficiency lessen by 2.53℃, 0.94 W and 0.84%, respectively for each 10% shading conditions of the PV module.
- Due to every 1°C growth of cell temperature, the power and efficiency of PV reduce to 0.01 W and 0.01%, respectively.

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