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DESIGN AND IMPLEMENTATION OF STAND-ALONE SOLAR STATION USING PV SYSTEM SOFTWARE

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ABSTRACT: With the growing concern about the greenhouse gas emissions and other environmental issues, the renewable energy technologies such as photovoltaic cells are increasingly being recommended for electricity production. In Sudan, the usage of a solar energy as a power generation connected to grid is very weak, almost non-existent. In this paper, an off-Grid energy system has been designed by constructing a solar power station. Two selected sites A and B in Atbara bridge engineering administration complex are taken as a case study to design two individual solar PV system to solve the problem of power outages and ensure the self-sufficiency of the bridge engineering administration complex. Shams application has been used to obtain the solar cell's angle. The PV system program is used to determine the optimum angle and to calculate the number of cells and the requirements of the system design. Small model was carried out with a small percentage of total designed load. Two experiments were conducted to determine the optimum cell orientation and cell angle.

KEYWORDS: Advantages and Limitations of Renewable energy; Availability of Solar energy in Sudan; PV module; Geographical location; Mathematical model; Design; Experiments.

1 INTRODUCTION

Sudan holds abundant renewable energy sources (RES). Its hydro resources are already being utilized or are under development. Besides the hydro resources, there is further RES potential through solar and wind energy, biomass and biogas, and geothermal energy [1], [2], and [3].

Solar photovoltaic (PV) power plants based on a range of semiconductor technologies, transform solar irradiation into electricity. The direct current produced by the solar power plant modules can run electric appliances or can be fed into the regular power system after being inverted into alternating current.

1.1 Advantages of renewable energy

PV power plants are relatively simple and modular technology with low operation and maintenance costs. Renewable energy at its large extent is a growing market expected to be worth more than $2 trillion by the end of the decade. From combating climate change and being an inexhaustible source of energy to the jobs it creates and the benefits it brings to the global economy, renewable energy has many benefits. Let's explore three of the main advantages of renewable energy.

1.1.1 Renewable energy is combating climate change

One of the main advantages of renewable energy is that it does not emit greenhouse gases, which are the main cause of climate change. Renewable energy sources, including wind and solar energy, help reduce the amount of carbon dioxide and other harmful pollutants in the atmosphere.

Renewable energy sources positively impact the environment because they help slow the disruption of plant and animal life, rising sea levels, extreme weather conditions, and other impacts associated with climate change. World leaders have even stated that by 2030 we must switch to renewables to make up 50% of our energy sources to help the planet reach net zero fossil fuels by 2050.

1.1.2 Sources of renewable energy are inexhaustible

Another major advantage of renewable energy sources is that they are inexhaustible because they originate from natural resources and processes that are constantly renewed. For example, sun, wind, the water cycle, and biomass waste are all elements used to produce renewable energy. These power sources can be used over and over again without being drained, making them extremely useful and reliable ever.

Unlike non-renewable energy sources such as fossil fuels, which are finite, renewable energy sources can be used to meet our energy needs for the foreseeable future, making them an essential part of the solution to the global climate crisis.

1.1.3 Creating renewable energy jobs and economic benefits

As mentioned, the renewable energy industry is growing. With this growth comes the need for talent to take on renewable energy jobs to complete projects and sustain efforts toward a net-zero future. In 2022, renewable energy jobs reached 12.7 million jobs worldwide, and the International Renewable Energy Agency (IRENA) expects this number to rise to 43 million renewable energy jobs by 2050.

The economic benefits of renewable energy are also important, not only by providing opportunities for talent within the industry to earn a good income. Renewable energy can also save businesses and consumers money. For example, as the cost of solar and wind energy declines, renewable energy is becoming competitive with non-renewable energy and, in some cases, cheaper. In the long term, renewable energy has the potential to stabilize energy prices for the global population.

1.2 Disadvantages or limitations of renewable energy

1.2.1 The initial costs for renewable energy installations are high

It is known that renewable energy technologies are still in their early stages of development. Therefore, the cost of equipment and installation is higher than it would be for more mature fossil fuel technologies available. For example, it costs approximately $1 million to produce one megawatt of electricity with a wind turbine, which is enough to power about a thousand homes annually.

However, as renewable energy technologies become more popular and resources become more widespread, these initial installations could continue to decline. For example, the costs of installing renewable energy technologies such as solar PV have fallen by up to 80% over the past decade, and these costs are likely to decline further over the next ten years.

1.2.2 Renewable energy is not always available during all the week's days

Although renewable energy sources are endless, they are not always available during all the week's days because they rely on natural resources. For example, if the weather is bad and the sun is not shining, the photovoltaic solar panels on rooftops that generate electricity from sunlight cannot work, resulting in homeowners having to revert to traditional, non-renewable alternatives.

Experts always take into account the geography of renewable energy projects and choose areas where the opportunity to generate energy is greatest. However, since nature can sometimes be unpredictable, this challenge may occur.

1.2.3 Significant space is needed for renewable energy projects

Having mentioned that geographical locations are taken into consideration when it comes to renewable energy projects, the space needed for these projects is large and not always viable or available for use in every country. For example, countries where the sun shines regularly can benefit from solar energy. However, they may miss the opportunity to produce this renewable energy source if the terrain conditions are not suitable or if other infrastructures already occupy the space.

1.3 Availability of solar energy in Sudan

Sudan provides an excellent base for solar photovoltaic power development. Its favorable geographic position provides comparatively high global horizontal irradiation of 1900 to 2500 kWh/m2/year (which is roughly twice the typical value for central Europe) throughout the country as seen in Figure 1.

PV will be applicable for the entire country for on- and off-grid solutions. In order to approach the existing network close to the major load center, PV-arrays can be arranged around Khartoum 220/ 110 kV - network ring allowing easy network access and smooth integration for electric power production. This has the potential to provide power where and when it is needed and to replace fossil fuel-based generation. In addition, PV-array distribution in smaller cities and villages will be the leading renewable approach for fast and smooth electricity production upgrade in rural areas, it has the potential to either replace more costly fossil fuel-based generation or provide power to previously unsupplied areas.

Economic growth for any country is measured by its sources of energy. Globalization and industrialization have led to depletion of nonrenewable sources of energy. All countries are now looking for alternative sources of energy, among them solar energy is one of the sources and its harnessing is growing in accelerating manner around the world. The total energy that can be intercepted from sun is 1.8 x 1011 MW, much more than the consumption needs of humans on this planet. Moreover, it is a clean and reliable source of energy that has the capability to meet the future needs [4]. With globally, increasing electricity demand and a desire to bring down CO_2 emissions in order to reduce the contamination in the air, a transition from fossil fuels to sustainable energy is needed. This objective has highly increased the installed capacity of grid-connected renewables such as wind and photovoltaics (PV) in modern power systems [5].

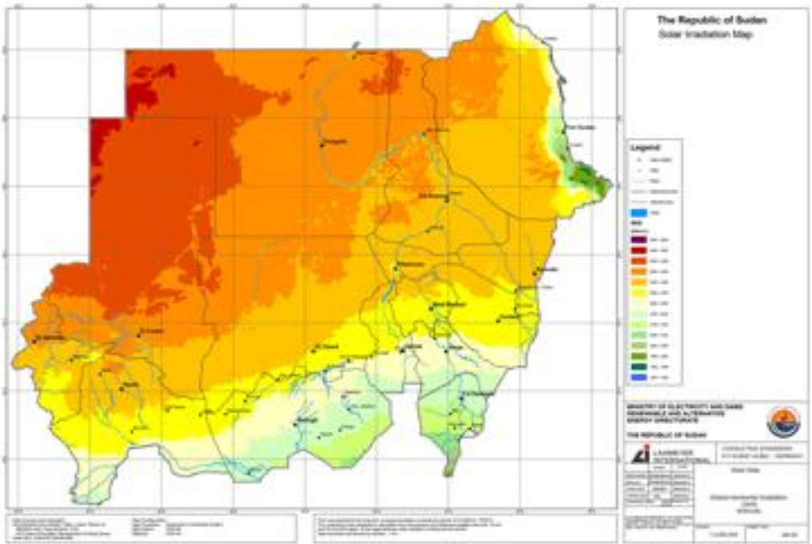


Figure 1. Sudan Global Horizontal Irradiation (GHI)

Recently, many photovoltaic (PV) systems have been connected to the grid due to the large increasing demand of greener and sustainable energy systems. However, the PV systems connected to the grid will enhance several challenges, e.g., grid stability and power quality issues [6].

Due to environmental factors, global warming and low fossil fuels, which affects the reliability of a power system, the world is turning to the alternative energies mainly renewable energies especially solar energy**.** A PV system consists of a PV array, battery and elements for power conditioning. The PV system converts solar energy into dc power. If AC loads are used this means, the system requires inverter to convert DC into AC. whereas, a stand-alone system involves no interaction with a utility grid, the generated power is directly connected to the load. In case the PV array does not directly supply a load, a storage device is needed, mostly this is a battery. The battery bank stores energy when the power supplied by the PV modules exceeds load demand and releases it backs when the PV supply is insufficient. This standalone PV power generation will be used in houses for the electrification purpose [4]. There are wide assortments of tools for the dimensioning and analysis of both Grid connected photovoltaic systems and stand-alone photovoltaic systems [4], [6], [7], and [8].

In this paper PV, system software is used to design the size of PV system and to calculate the number of cells and the needs of the system. Shams application has been used to obtain the solar cell's angle in Atbara city.

2 PV MODULE

Two types of a PV system are used in power system such as Grid-Connected (GC) PV system and Stand-Alone (SA) PV system. The GC photovoltaic systems feed electricity directly to the Grid, operating parallel to the energy sources. (GC) systems generate clean power near the point of use, without the transmission and distribution losses or the need for the batteries. While stand-alone system is not connected to, any grid and can have capacities from few milliwatts to several kilowatts. Stand-alone system work on batteries and have solar modules, controller and inverter as main components [4], [9], [10]. The mounting structure is made, over which solar modules are mounted and they produce DC power. Controller has dual function to perform; one is to charge the battery and second is to prevent overcharging batteries. They eliminate any of the reverse current flow from batteries back into the solar modules during night. The energy stored in the battery during daytime can be used anytime, day and night. The inverter can invert the energy stored in the battery to AC current to run AC appliances [4], and [9]. In this paper, the stand-alone PV system as is shown in Figure 2 is used.

2.1 Solar power

A solar PV system uses solar panels to convert energy from the sun into electrical energy. Solar panels are composed of a number of solar cells that contain semiconducting materials, which exhibit photovoltaic effects [11]. High efficiency of energy conversion is obtained when the PV panel is operating at its maximum power point [12]. In a PV system, the electricity generated by solar cells can be given as in [11], and [13].

$$P_{pv}(t) = GHI(t) \times S \times \eta \quad (1)$$

Where: GHI is global horizontal irradiation (W/m^2), S is surface area of solar panels (m^2), and η is the conversion efficiency of PV cells. Typical solar panels according to MacKay [8] have efficiency of about 10%. More expensive one with tracking device have efficiency up to 20%. In our work, we use PV Watts of National Renewable Energy Laboratory (NREL) that takes 15% as the efficiency of solar panels [11].

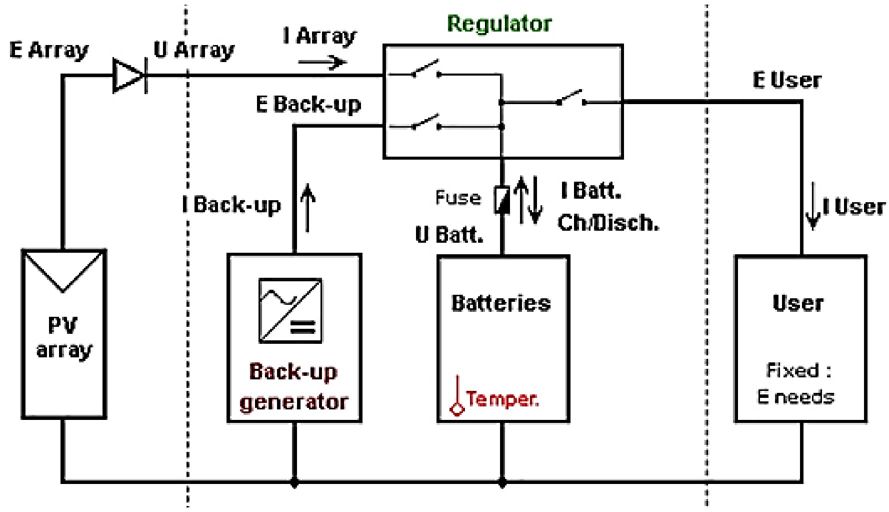


Figure 2. Layout of stand-alone PV system

2.2 Storage

Now a day, common storage technologies are used. Among electrochemical storage technologies, most common battery types are lead-acid and lithium-ion batteries. These batteries have less cost per kWh and commonly used in different applications such as micro-grids and electric vehicles. Its maximum capacity, Depth of Discharge, charging and discharging times, efficiency and other parameters as described in [14], and [15] can characterize a battery. A battery charging and discharging processes can be expressed as in the following references [11], [16] and [17]:

$$b(t+1) = \begin{cases} b(t) + \Delta t P_{bat}^{c}(t)\eta_c \\ b(t) - \Delta t P_{bat}^{d}(t)/\eta_d \end{cases} \quad (2)$$

Where: $b(t)$ represents the state of the battery at time t; $P_{bat}^{c}(t)$ is charging power; $\Delta t P_{bat}^{d}(t)$ is discharging power; Δt is time step of charging or discharging process; η_c and η_d are charging and discharging efficiency respectively. For normal operations of a battery, different constraints are imposed on power and energy limits. For example, stored energy cannot be greater than its predefined capacity C, i.e.,

$$C_{min} \leq b(t) \leq C$$

Furthermore, there exists a limit on charging and discharging power rates, i.e.,

$$0 \leq P_{bat}^{c}(t) \leq P_{bat}^{c,max}(t)$$

$$0 \leq P_{bat}^{d}(t) \leq P_{bat}^{d,max}(t)$$

$$P_{bat}^{c,max}(t) \text{ and } P_{bat}^{d,max}(t)$$

represent maximum charging and discharging limits at any given time *t*.

3 GEOGRAPHICAL LOCATION AND SOLAR HORIZON

The bridge subjected to the current study is placed in Atbara City, which lies between 17.14 N latitude and 33.59 E longitude. The tilt angle for PV array is kept as equal to the latitude of the corresponding location to get maximum solar Irradiation [4], [18], and [19]. So that the optimum tilt angle for Atbara is kept as 15^0.

4 MATHEMATICAL MODEL

The characteristics of the proposed photovoltaic cells are as shown in Table 1 below.

Table 1. Characteristics of the photovoltaic modules under standard conditions

Rated maximum power, P_{max}	$300\ W$
Open circuit voltage, V_{oc}	$44.6\ V$
Maximum - power voltage, V_{mp}	$36.1V$
Short circuit current, I_{sc}	$8.8\ A$
Maximum - power current, I_{mp}	$8.3\ A$

The total dc power of the station is:

$$P_{dc} = \frac{E}{P.F} \tag{3}$$

Where: E is the total energy of the station MWh/day and $P.F$ is the power factor.

The Peak power current $I_{mp}.h/day$ for the system is given by:

$$I_{mp} = \frac{E}{Vsyst} \tag{4}$$

Where: $Vsyst$ is the nominal voltage of the photovoltaic cell.

The Peak power current $I_{mp}.h/day$ for the batteries is given by:

$$Amp.h/day\ for\ batteries = Amp.h/day \times safety\ factor \tag{5}$$

$$PVcurrent = \frac{\frac{Amp.h}{day}\ for\ batteries}{radiation\ hours} \tag{6}$$

$$\text{Number of module in parallel} = \frac{total\ PV\ array\ current}{mod\,u\,le\ operating\ current \times mod\,u\,le\ factor} \tag{7}$$

$$\text{Number of module in series} = \frac{system\ nominal\ voltage}{module\ nominal\ voltage} \tag{8}$$

$$Total\ modules = modules\ in\ series \times modules\ in\ parallel$$

5 THE DESIGN

The bridge engineering administration complex is fed with electricity from two transformers in two different directions. In this section, to calculate the load of the stations, firstly, we go back to the feeders, which feed the load of the station side, and which is supplied from the transformers of the bridge. Secondly, we calculate all the energy of the devices, which are used in each site.

5.1 Site A

This site includes the buildings of civil engineering laboratories, meeting halls and resting rooms, the cafeteria, hydraulic machines laboratory, civil and mechanical engineering maintenance workshops. Table 2 below shows the calculated loads of site A. To identify the total power and total energy of the station the PV system program is used as shown in Figure 3 below.

Table 2. Loads of site A

Device Name	Number	Device Wat	Daily Use Hours	Total Power KW	Total Energy KWH
Lamp	140	15	9	2.100	18.900
Fan	74	75	9	5.550	49.950
Air Condition	31	1340	9	41.540	373.860
Computer	33	330	9	10.890	98.010
Printer	0	650	0	0	0
Copying Machine	2	1500	10	3.000	30.000
Total	——	——	——	63.080	570.720

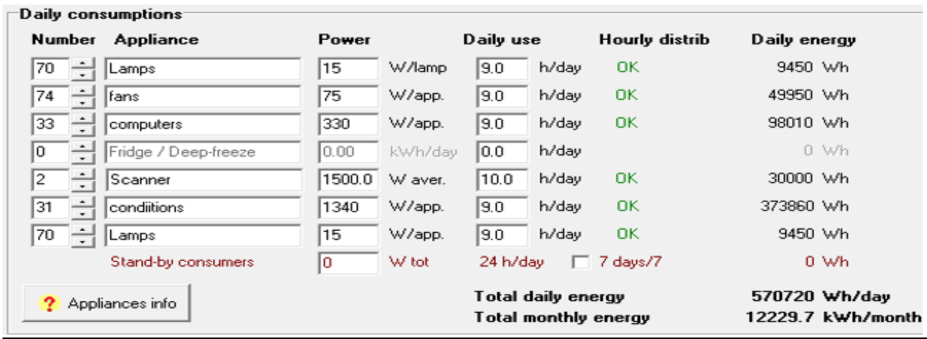


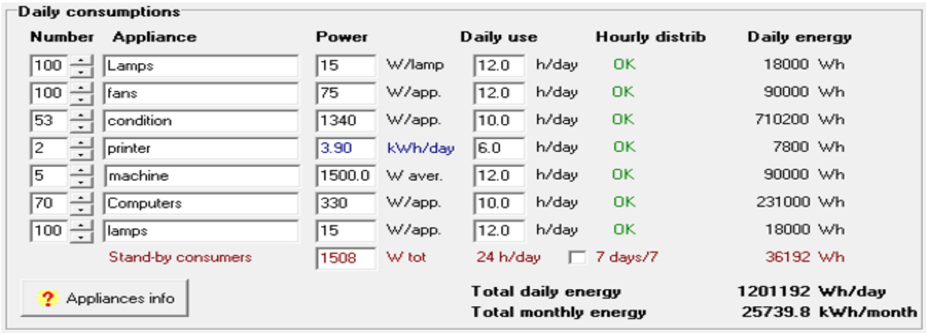
Figure 3. Site A loads using PV system

5.2 Site B

Site B includes the following building: the manager and deputy manager offices, senior staff offices, junior staff offices, accountants and sore keepers' offices and sores. Table 3 below shows the calculated loads of site B. To identify the total power and total energy of the station the PV system program has been used as is shown in Figure 4 below.

Table 3. Loads of site B

Device Name	Number	Device Watt	Daily Use Hours	Total Power KW	Total Energy KWH
Lamp	251	15	12	3.765	45.180
Fan	130	75	12	9.750	117.000
Air Condition	53	1340	10	71.020	710.200
Computer	70	330	10	23.100	231.000
Printer	2	650	6	1.300	7.800
Copying Machine	5	1500	12	7.500	90.000
Total	——	——	——	116.435	1201.180


Daily consumptions

Number	Appliance	Power		Daily use		Hourly distrib	Daily energy	
100	Lamps	15	W/lamp	12.0	h/day	OK	18000	Wh
100	fans	75	W/app.	12.0	h/day	OK	90000	Wh
53	condition	1340	W/app.	10.0	h/day	OK	710200	Wh
2	printer	3.90	kWh/day	6.0	h/day	OK	7800	Wh
5	machine	1500.0	W aver.	12.0	h/day	OK	90000	Wh
70	Computers	330	W/app.	10.0	h/day	OK	231000	Wh
100	lamps	15	W/app.	12.0	h/day	OK	18000	Wh
	Stand-by consumers	1508	W tot	24 h/day		7 days/7	36192	Wh
	Appliances info			Total daily energy			1201192	Wh/day
				Total monthly energy			25739.8	kWh/month

Figure 4. Site B loads using PV system

6 EXPERIMENTS

Small model was carried out with a small percentage of total designed load. Two experiments were conducted to determine the cell's orientation and angle with cell's output. The experiments were conducted in August during autumn season. The characteristic of the photovoltaic cells model is placed in Table 4. Figure 5 shows the solar module. Table 5 shows the system components of the solar module.

Figure 5. Solar module

Table 4. The characteristic of the photovoltaic cells

Rated maximum power Pmax	5W
Open circuit voltage Voc	10.8 V
Maximum - power voltage Vmp	8.8 V
Short circuit current (Isc)	0.62 A
Maximum - power current Imp	0.57 A

Table 5. System components

Name	Specifications	Number
Cell	5W	12
Controller	20A	1
Battery	42A	1
Inverter	300W	1
Cable	$0.3mm^2$	10m
	$1.5mm^2$	15m
Lamp	8W	6
Fan	21W	1

6.1 Results of the first experiment

The first experiment is conducted to determine the cell output with the change of cell's orientation i.e. direction south, east, north and west. In this experiment, the tilt angle is fixed at 15^0. The readings were taken in different directions hourly during the daytime from nine in the morning until six in the evening over seven consecutive days. The average readings were taken for the seven days as shown in Table 6 below.

Table 6. Average output power of the cells at different directions

Time	POWER (W)			
	South	East	North	West
09:00	19.305	9.6975	21.2382	8.514
10:00	31.5198	25.802	28.944	15.3738
11:00	37.2625	34.3662	41.208	28.1523
12:00	44.9757	43.766	43.5204	43.47
13:00	42.9248	47.415	40.749	48.4915
14:00	36.9272	45.0114	28.6234	48.0495
15:00	14.707	18.69	7.6908	24.4244
16:00	10.1634	7.9971	5.418	11.3796
17:00	3.0061	2.7447	2.3544	3.1392
18:00	1.0408	1.04	1.17	1.1709

Table 6 shows the average output power of the cells for the seven days' hour by hour in the different directions. South, east, north and west. It is observed that from 9:00 AM to 12:00 PM o'clock, the cells output at the south and north directions are better than the other directions. However, from 01:00 PM o'clock to the end of the day, due to the tilt of the sun towards the cells, and because of the good ventilation of the cells and high radiation, the west and east direction are the better, but the west orientation is the best one.

Figure 6 shows clearly the average values relating the cells output in watt with change of the directions for seven individual days.

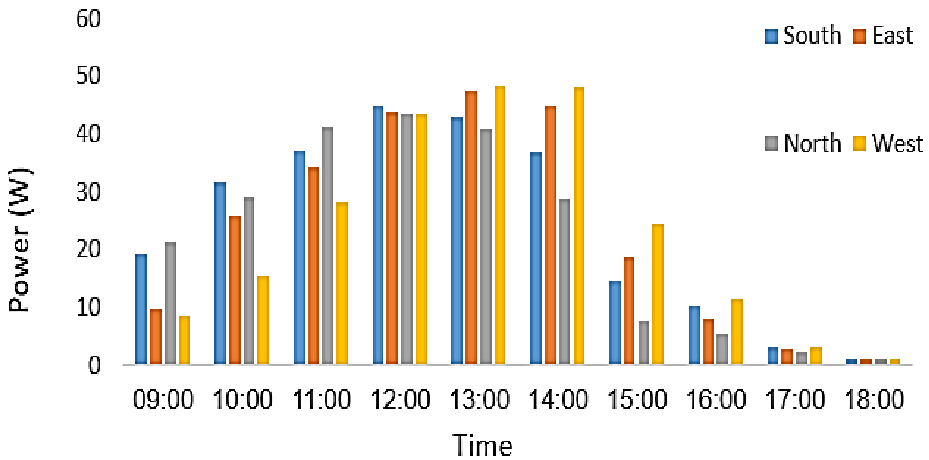


Figure 6. Cell's output power for the four directions

6.2 Results of the second experiment

This experiment is a study of the effect of changing the angle of inclination on the output of cells. In the beginning, the angle of the inclination was set at 0^0C and then changed gradually to an angle of 35^0C with an interval of 5^0C in south direction. The readings were taken every hour during the daytime from ten in the morning until six in the evening, over six consecutive days. The average readings, which were taken for the six days, are shown in Table 7 and Figure 7 below.

Table 7. Average output power of the cells at different angles

Time	**POWER (W)**							
	0^0C	**5^0C**	**10^0C**	**15^0C**	**20^0C**	**25^0C**	**30^0C**	**35^0C**
10:00	36.12	35.84	34.272	33.728	32.776	31.824	29.729	27.885
11:00	50.887	51.189	48.672	48.096	46.761	45.188	41.89	37.488
12:00	57.876	57.876	56.52	54.912	51.832	48.9	44.104	39.516
13:00	54.72	53.454	52.548	50.85	45.445	39.712	31.244	28.71
14:00	54.352	52.839	66.068	44.173	36.96	29.987	23.254	18.542
15:00	10.295	9.996	13.764	17.374	16.905	25.16	31.82	15.73
16:00	8.208	8.294	8.437	8.265	7.83	7.592	7.105	6.816
17:00	4.158	4.312	4.466	4.774	4.64	5.115	5.236	5.115
18:00	1.41	1.41	1.41	1.833	1.41	1.551	1.41	1.269

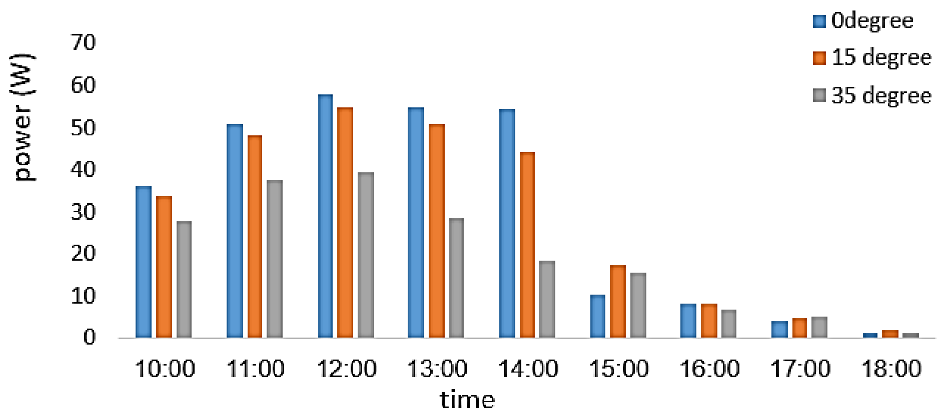


Figure 7. Cell's output power for the three different angles

Table 7 shows the average output power of the cells for the six days' hour by hour at different angles. It is observed that the cells output from 10:00 AM to 14:00 PM o'clock, the smaller the angle, the better the cell output. During the fall season, the eighth month of the year (i.e. August), the sun is close to being vertical. The worst reading is at the angle of 35^0C, which means that the tilt angle of the cell is not greater than 15^0C.

7 CONCLUSIONS

This research paper introduced the study of required load to run Atbara bridge engineering administration complex as shown in Table (2) and Table (3). Accordingly, the photovoltaic station is designed. Furthermore, from the PVsyst program study, the total daily energy required for the two sites A and B are 570.720 KWh and 1201.180 KWh respectively, and the total power requirements in KW are 63.080 KW and 116.435 KW respectively. From the results of the experiments, it is concluded, that to achieve the better output power, the best tilt angle must not be greater than 15^0C and the better orientation is the south direction.

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