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Design and Calculations of a Solar PV System for the University of Technology

Dr. Kareem K. Jasim
Energy of Renewable Technology Center, University of Technology

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ABSTRACT: In this research a proposed efficient PV solar system was designed and calculated for a building in the University of Technology. An approximate estimation of the cost required to build the solar system was done. Solar energy is readily available anywhere and everywhere in the earth. It can be used it to generate electricity at the point of consumption. Solar powered building is based on this concept. Considering the above aspects, solar power option for the Technology University is being studied in this work as well. The objective of this work is to estimate the potential of grid quality solar photovoltaic power in Al-Wahda district of Baghdad and finally develop a system based on the potential estimations made for chosen area of 100 m2 . Annual energy generation by proposed system is also calculated. In the last cost estimation of the system to show it is economically viable or not.

الخلاصة:
فى هذا البحث تم تصميم منظومة شمسية لتزويد بناية مفترضة من بنايات الجامعة التكنولوجية بالطاقة الكهربائية الفولطائية . كما تم اجراء جميع الحسابات التى تحتاجها مكونات المنظومة المقترحة. ولكون الطاقة الشمسية متوفرة فى اى وقت واى مكان فى بلادنا لذلك يمكن استغلال هذه الطاقة فى تزويدنا بالطاقة الكهربائية النظيفة ولتقليل استهلاك الطاقة من الشبكة الوطنية. كما يهدف العمل الى تحديد القدرة المتولدة من الشمس فى حى الوحدة التابعة لمحافظة بغداد وعلى مساحة 100 مترمربع. وتم حساب الطاقة السنوية للمنظومة وتحديد كلفتها الكلية.

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1. INTRODUCTION

1.1Similar Projects:

Commercial buildings, houses, offices, companies are installing solar system for green energy such as the largest solar powered building in Province in northwest China [7].

(Figure 1): The largest solar power building in northwest china

The above picture is the largest solar powered building and it will be the venue of the 4th world solar city congress. We can also see 100% solar powered buildings. Like the stadium for the world game 2009 in Taiwan was 100% solar powered.

Figure (2): 100% solar powered stadium in Taiwan.

The fig.(2) shows that the 100% solar powered building in Taiwan. It has 8,840 solar panels in the roof and can produce 1.14 million kWh/year. By this it can prevent 660 tons of carbon dioxide to release in the environment [8].

1.2Potential of solar energy:

There is a huge potential of solar energy. It is so huge that the total energy needs of the whole world can be fulfilled by the solar energy. The total energy consumption of the whole world in the year 2008 was 474 exajoule (1EJ=1018 J) or approximately 15TW (1.504*1013 W). [11] Almost 80%-90% of this energy came from fossil fuel. [12].

1.3 Solar panel:

A solar panel consists of number of photovoltaic (PV) solar cells connected in series and parallel. These cells are made up of at least two layers of semiconductor material (usually pure silicon infused with boron and phosphorous). One layer has a positive charge; the other has a negative charge. When sunlight strikes the solar panel, photons from the light are absorbed by the semiconductor atoms, which then release electrons. The electrons, flowing from the negative layer (n-type) of semiconductor, flow to the positive layer (ptype), producing an electrical current. Since the electric current flows in one direction (like a battery), the electricity generated is DC.

1.4 Types of solar system design:

There can be various types of solar system design. But there are three basic design consideration, they are:

1. Grid tie
2. Off-grid
3. Stand alone

2. Solar PV technologies:

With the growing demand of solar power new technologies are being introduced and existing technologies are developing. There are four types of solar PV cells:

- Single crystalline or mono crystalline
- Multi- or poly-crystalline
- Thin film
- Amorphous silicon

Table1: Efficiency of different types of solar cells

Cell type	Efficiency, %
Mono crystalline	12 – 18
Polycrystalline	12 – 18
Thin film	8 – 10
Amorphous Silicon	6 – 8

3. Components of a solar PV system

A typical solar PV system consists of solar panel, charge controller, batteries, inverter and the load. Figure 2 shows the block diagram of such a system. Figure (3). Block diagram of a typical solar PV system.

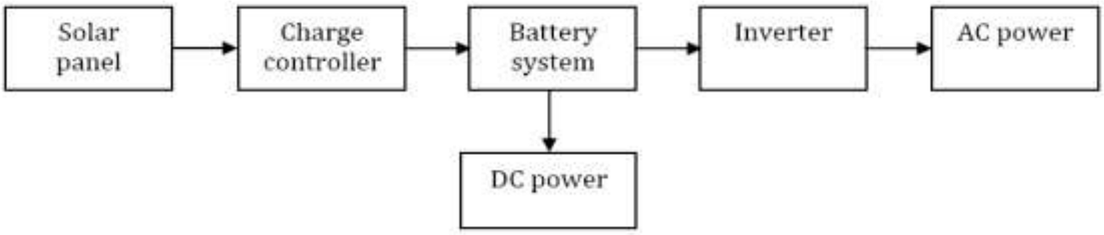

Figure (3): Block diagram of a typical solar PV system

3.1. Charge controller:

When battery is included in a system, the necessity of charge controller comes forward. A charge controller controls the uncertain voltage build up. In a bright sunny day the solar cells produce more voltage that can lead to battery damage. A charge controller helps to maintain the balance in charging the battery. [14]

3.2. Batteries:

To store charges batteries are used. There are many types of batteries available in the market. But all of them are not suitable for solar PV technologies. Mostly used batteries are nickel/cadmium batteries. There are some other types of high energy density batteries such as- sodium/sulphur, zinc/bromine flow batteries. But for the medium term batteries nickel/metal hydride battery has the best cycling performance. For the long term option iron/chromium redox and zinc/manganese batteries are best. Absorbed Glass Mat (AGM) batteries are also one of the best available options for solar PV use. [15]

3.3. Inverter:

Solar panel generates dc electricity but most of the household and industrial appliances need ac current. Inverter converts the dc current of panel or battery to the ac current. We can divide the inverter into two categories. [16] They are:

- Stand alone and
- Line-tied or utility-interactive

4. Load survey of The University of Technology:

Finding out and understanding the total energy consumption of the University is the first step through designing an Energy Program for the University of Technology. In this part we observed the data of energy consumption figures and facts of the University. We collected the peak and off peak data. We analyzed the monthly load from October 2013 to September 2014.

4.1. Technology University electrical energy consumption:

Annual electrical energy consumption of BRAC University is 28, 62, 880 kWh. The total off peak energy consumption is 22, 80, 400 kWh and the peak energy consumption is 5, 82, 480 kWh. Average energy monthly consumption including off peak and peak is 2, 38, 573 kWh. [17]

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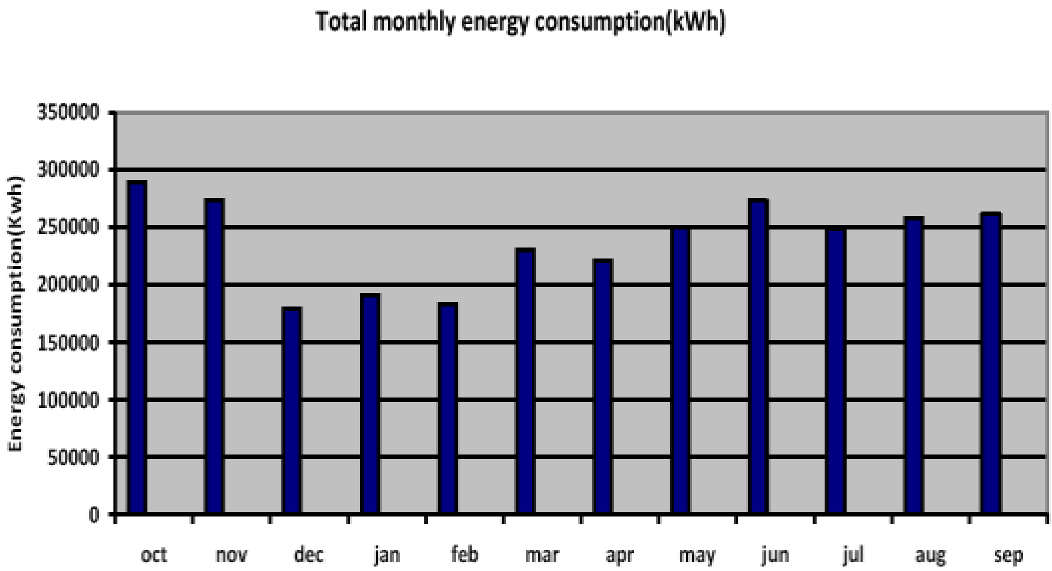
4.1.1. Technology University monthly energy consumption:

By using the data of monthly electricity bill of Technology University we can determine the monthly, yearly and average energy consumption by Technology University. Beside we can show the peak and off-peak energy consumption.

Peak-hour: peak hour is from 6pm to 11pm Off-peak hour: off-peak hour is from 12am to 5pm. The data of monthly, monthly average and peak off-peak energy consumption Technology University is given bellow in figure no.(4).



Figure(4) Monthly energy consumption from October 2013 to September 2014

4.1.2. Irradiance and insolation:

Insolation: Insolation is the amount of solar energy that strikes a given area over a specific time and varies with latitude or the seasons [19].

Irradiation: Irradiance means the amount of electromagnetic energy incident on the surface per unit time per unit area. so the total solar irradiation is defined as the amount of radiant energy emitted by the sun over all wavelengths that falls each second on 1m^2 (11 ft^2) outside earth's atmosphere [19]

Irradiance of a site is given by the following relation:

$$Irradiance = \frac{Average\ Insolation}{Average\ daily\ bright\ sunshine\ hours},\ kWh/m^2$$

It is very important to know the irradiation and insolation of a site when anyone is going to design a solar PV system for that site. Depending on the sun shine, irradiance and insolation varies with place to place.

The daily average bright sunshine hours in Baghdad city is 7.55 hours and the average solar insolation is 5.24 kWh/ m^2
.

From formula, we get the irradiance of Baghdad city is 694.04 watt/m^2 . This value will be used for University solar PV system design.

5. Technology University solar PV system design:

5.1. System configurations:

There are many possible configurations of solar PV system. Each of these configurations has its own advantages and disadvantages. Depending on the system requirements appropriate system configurations has to be chosen. In our work, at first we considered two possible configurations for Technology campus. The first one is grid connected solar PV system without battery (Figure (5) (a)) and the second one is stand alone solar PV system with battery (Figure (5) (b)).

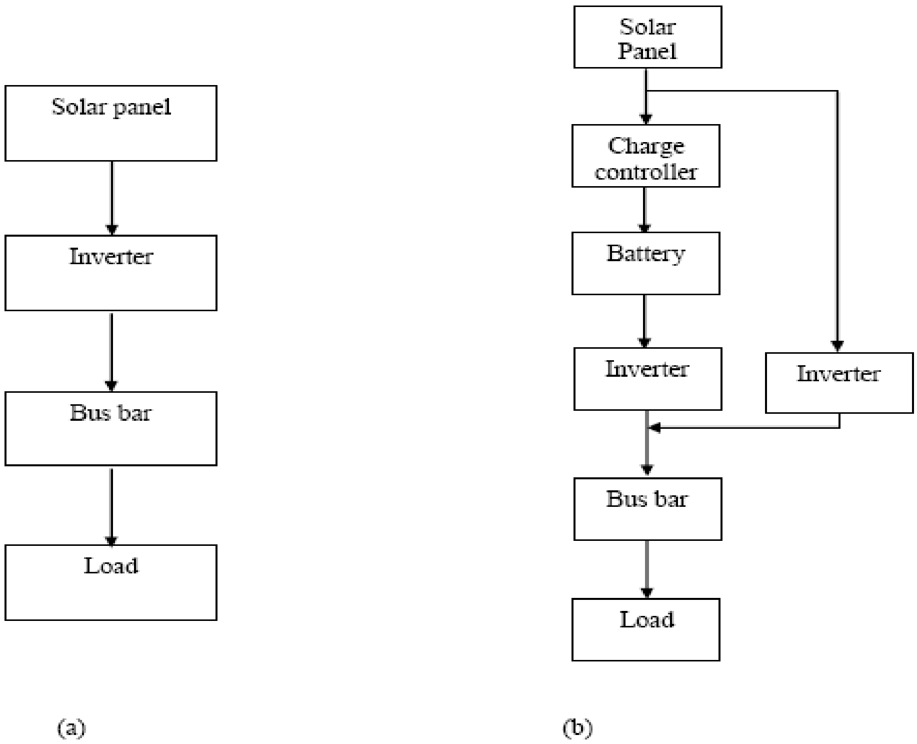


Figure (5): (a) and (b) possible configurations of solar PV system for the university

Figure (a): The block diagram (a) shows the design configuration where the solar panels will be connected to inverters, then the inverter current will be supplied to the university's bus bar then to the load.

Figure (b): The block diagram (b) shows a design configuration that can both supply and store energy. When the demand is high the then the system will deliver energy same as the block diagram (a) as described. But when the demand is low or in a off day the battery can store energy by solar panel through charge controller. This stored energy can be used as backup for gloomy day or at night.

But we need huge amount of energy to run the University. Monthly average energy consumption of BRAC University is 238,573.33 kWh and we can theoretically produce 19335.607 kWh per month.
At 694.04 W/m^2 insolation the selected PV module can produce = 173.51 W
Daily average bright sunshine hour = 7.55
Total no. of modules = 492
So, the monthly energy generation = 173.51*7.55*492*30 = 19335.607 kwh/month
As this is a huge difference with the University's monthly energy consumption we can not store extra energy.
Therefore, we choose the block diagram (a) for our proposed system.

5.2. Selecting the PV module:

As we need huge power supply and we do not have huge area. So, we selected mono crystalline silicon module. Our module selection depends on cost and efficiency.

The capital investment of solar PV panel is very high. Approximately, 60% of the total system installation cost is the price of module cost. We should consider the cost in order to get the best output of the money spent. Cost varies on efficiency of panel and the material has been used to make the PV panel. The cost of silicon solar cell is very high. In our design we used mono crystalline silicon cell.

Efficiency of solar cell depends on the technology used. Silicon solar cell has the highest efficiency. Thin film has low efficiency, but they can be ideal for some applications. Another important consideration is temperature. Module efficiency decreases as the module temperature increases. When modules operating on roof, it heats up substantially. Cell inner temperature reaches to 50-70 degree Celsius. In high temperature areas, it is better to choose a panel with low temperature co- efficient.

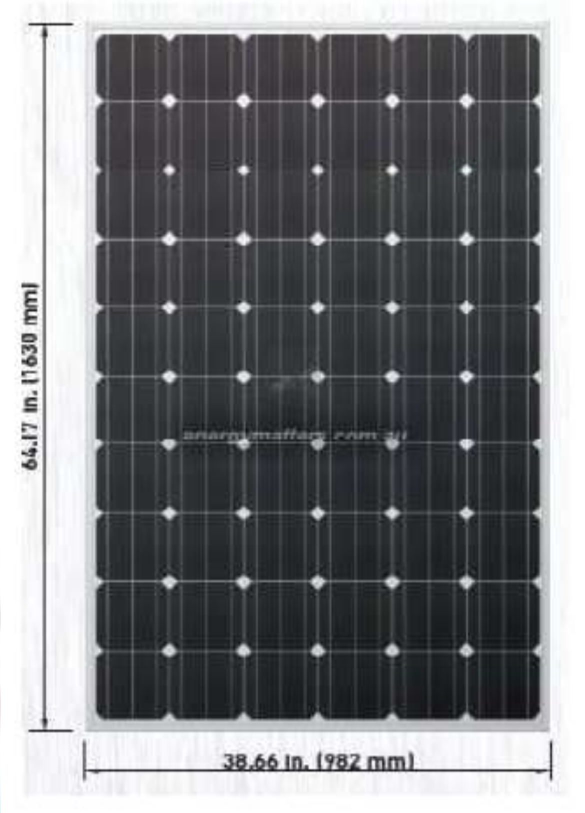


Figure (6): Samsung LPC250S solar module

Fig. (6) shows the Samsung solar module and the model is LPC250S. Its maximum output power is 250 watt. If irradiance is 1000 watts per meter square then the module's nominal power output is 200 watt if irradiance is 800 watts per meter square. The irradiance of Baghdad City is 694.04 watts per meter square. So we will get power less than 200 watts, approximately 173.51 watts. 25 years power output warranty is 80%. The panel efficiency is 15.62%. Short circuit current of the panel is 8.66A at standard test condition and 6.90A at nominal condition. [20]

5.3. Inverter selection:

Figure (7): ZONZEN ZZ-ZB 10kW grid tie inverter

We selected a PV grid tied inverter. The model is ZZ-ZB10kW. [21].

- The MPPT voltage range: 100-150 V
- Output power: 10kW
- Connection: 50Hz grid frequency and 3 phase 4 wire connection
- The efficiency of this inverter: 97%.
- AC voltage: 230 Volt.

5.4. System sizing:
In this section we will select the number of PV module can be installed in the selected area. The no. of inverter, combiner box and other equipments is needed to complete the whole designing .we will also find that.

5.4.1. Number of module selection:
The no of module can be accommodate on both roof top and facade can be calculated by the following formula, No. of module accommodation =Total usable area/area of a selected PV module
By using this formula we get:

Table (2): Possible number of modules using rooftop and façade area

Panel installation location	Usable area(m^2)	No. of modules
Roof top	408	252
Facade	380.50	240
Total	788.50	492

5.4.2. PV array designing:

To design the array there are some parameter to check. The most important thing to choose proper inverter and combiner box. So that, they can withstand the PV modules' voltage and current. The 10kW inverter's MPPT voltage range = 100-500 V

PV module's open circuit voltage = 37.6 V
12 module in series = 37.6* 12= 451.2 V

This is within the inverter's MPPT voltage range. We didn't put more module due to safety.
Module's maximum power voltage = 30.9 V
Inverter MPPT voltage range : 100-500V.
(100-500V)/12 = 8.33-41.66 (module maximum power voltage = 30.9)

So, power maximum power voltage is in the inverter's voltage range.
The 10kW inverter's current rating:
Inverter's rated voltage = 360 V
Maximum current : (10000/360) = 27.77 A
At 694.04 W/m2 maximum short circuit current =6.01 A

If we put 3 parallel string (1 string consist of 12 series module) = 3*6.01= 18.03 A
We can not put more string, because if there rise a weather condition with low temperature and high insolation excessive current can flow.
For safety considering 35% excessive current = 24.34 A
This is also in inverter's capacity
The combiner box maximum input fuse rating = 600 V , 20A
This is also can withstand 3 parallel string each consist of 12 series modules

Therefore, our chosen PV array design is 3 parallel string each consist of 12 series modules for 1 combiner box and 1 inverter.
As we need to arrange 492 modules we need such 14 configuration.

5.4.3. Number of inverter calculation:
No of inverter =Total no of module/(no. of module in series in a string*no. of parallel string)= 492 / (12*3)= 13.66= 14

5.4.4. Number of combiner box:
We will need combiner box is equal to the number of inverter. So, we will need 14 combiner boxes.

5.4.5. Wiring:

Rated short circuit current is 8.66 A from the PV module. If there is a effect of higher insolation and lower temperature access current can flow. To prevent these to happen the safety factor is considered. Average insolation at Dhaka city is 694.04 W/m^2 .

Therefore maximum short circuit current will be = 6.01 A
For 3 parallel string = 3*6.01= 18.03 A
Considering 35% safety factor Maximum current rating is 25 A.

So, we have chosen 25A rating wiring.

5.4.6. Energy supplied by the proposed PV solar system:

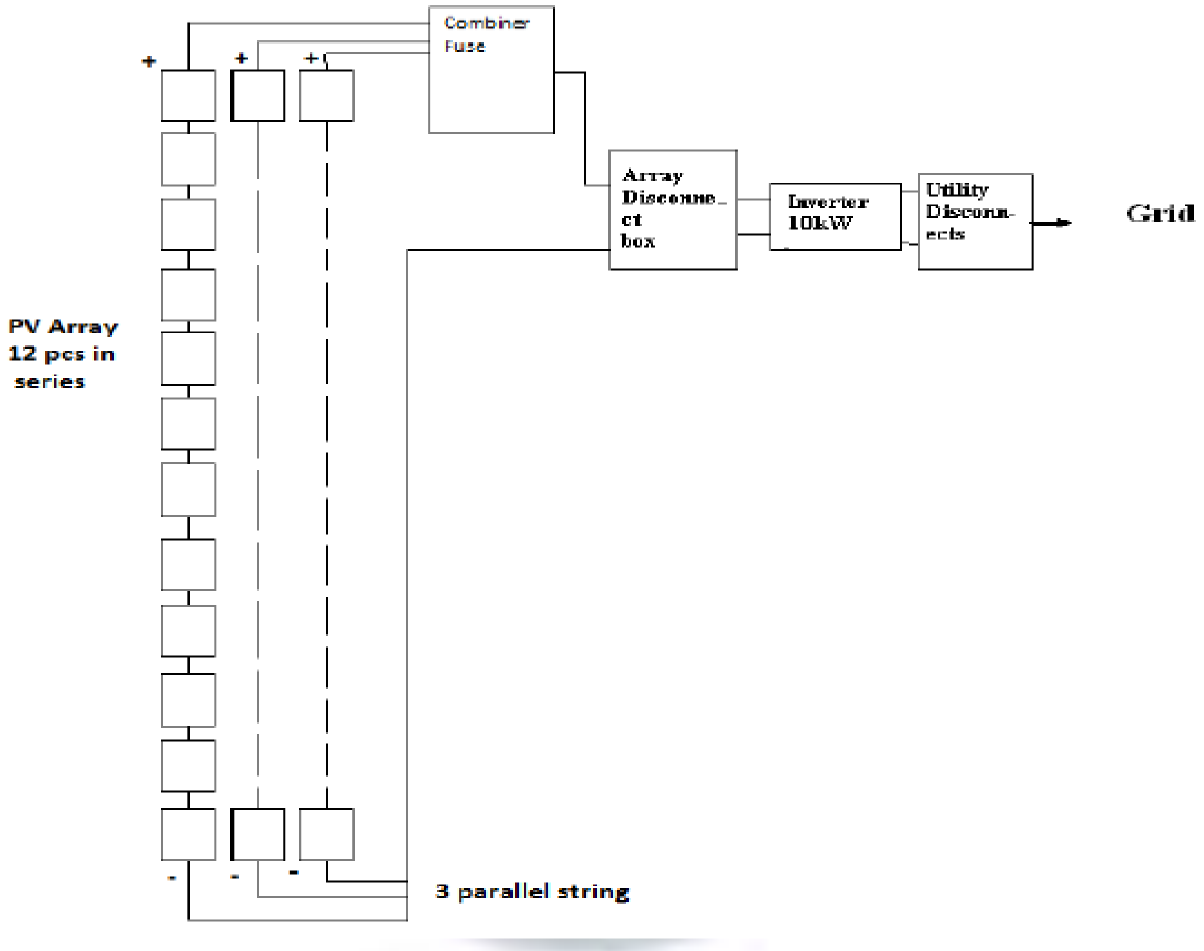


Figure (8): Designed Solar PV system

The figure (8) shows the designed solar system of BRAC University. This configuration showing that there is one combiner connected with 36 PV module. 12 PV modules in series in a string and there are 3 strings in parallel. For our system there would such 14 configuration.

The solar irradiance in Baghdad is 694.04 watt/day . The energy supplied by the solar PV system in a year can be found by the following formula.
Total energy supply = Maximum Power at defined irradiance of a solar panel *Average bright sunshine hour * 365 days * total no. of solar panels
= 173.51 * 7.55 * 365 * 492
= 235.249 MWh/year

Considering 80% of panel's output efficiency the total energy supply = 188.39 MWh/year

The daily output energy is 515.62 kWh/day

Cost Calculation

To implement the proposed solar PV system for the university campus, we need to have a clear concept on the implementation cost. In these consequences, we have calculated the approximation cost in I.D. Table(3) shows all components that we have required implementing a solar PV system. These components are: PV modules, inverters, combiner boxes, and surge arrestors, lightning rod, mounting, meters, wiring .also we have to consider the transportation, installation, LC and maintenance costs. We have considered this as the 40% of all components costs. After doing calculation the total cost stands around 730 million I.D.

Table (3): The cost of all the components of the designed system

Component	Description	Quantity	Cost(I.D)
PV module	Samsung LPC250S	492	420 ,140, 000
Inverter	ZONZEN ZZ-ZB10kw	14	50 ,400 ,000
Combiner Box	SMA SCCB-10	14	8,148,000
Surge Arrester	-	14	1,440,000
Lighting Rod	-	2	240,000
Mounting	-	-	37,713,600
Meters	-	-	36,000
Wiring	-	-	3,600,000
Transportation, installation, LC, maintenance	40% of all costs	-	208,686,000
Total cost			730,403,000

Conclusion

We are facing fuel shortage for electricity generation and in the near future the whole world going to face the same scarcity because of world's limited fuel stock. So worldwide renewable energy demand and research are rising and our government also taking steps for green energy. So, we choose solar energy for the University of Technology as secondary energy source.

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