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ANALYSIS OF OPTIMUM TILT ANGLE OF SOLAR POWER PLANT IN MINBU (MAGWAY REGION)

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Abstract

The photovoltaic (PV) panel performance is mainly influenced by its tilt angle, orientation, climatic conditions and geographic location of solar panels, which are used to get the maximum conversion of sunlight into solar electricity. In order to have maximum annual average incident solar energy on the surface of PV system, it is required to determine the optimum tilt angle. Optimization of tilt angle ensures the maximum energy generation output and area of PV modules were calculated. Several simplified design procedures for solar energy systems require monthly average meteorological data. In this paper proposes an algorithm to calculate the optimum tilt angle of solar panels method was developed by S. A. Klein by using NASA Solar Radiation Data Base, consisting of solar radiation and meteorological data all over the world. The output power of solar PV modules with the various incident angle of solar radiation was determined. According to the results, the average optimum angle (the best angle) of inclination of the solar panels is $\beta = 25^{\circ}$ for Minbu solar power plant in Magway region. After completion of study, an optimum plan can be formulated for practical set ups which can lead to maximum efficiency of solar power generation.

Keywords: photovoltaic (PV), solar panel, optimum tilt angle, solar radiation, solar energy, maximum output power

Introduction

Solar energy is the energy derived from the sun, when the sun's radiation reaches the earth's atmosphere; it is converted into other forms for the production of electricity. Solar energy resource data is necessary for the evaluation of the profitability of installing photovoltaic (PV) plants. The total solar radiation data is scarce in some locations, this is due to the absence of meteorological measurement stations and remote data collection networks, whose installation is expensive. Total measured solar radiation data are the best source of information for estimating average incident radiation necessary to calculate the productivity of an installed solar energy systems. In order to evaluate the production of a photovoltaic solar power plant, in a given region, must be made over a period of at least 11 years. In this paper, obtaining geometry information from National Aeronautics and Space Administration (NASA) surface meteorology and solar energy - available tables over 22-year average.

A critical parameter for installing fixed-tilt panels is the tilt angle, since PV panel output increases with increasing exposure to direct sunlight. Energy modelers also need to know the optimal tilt angle of a panel for calculating regional or global PV output in a given location or worldwide. Many studies have provided equations that allow for the theoretical calculation of the optimal tilt angle over time of a solar collector based on earth-sun geometry. Currently, many research works are carried out focusing on optimization of PV systems. The aim of this study was to propose an algorithm for the determination of the optimum tilt and orientation of a solar panel using a calculation model based on the orientation of a generic surface with respect to the position of the sun in the sky.

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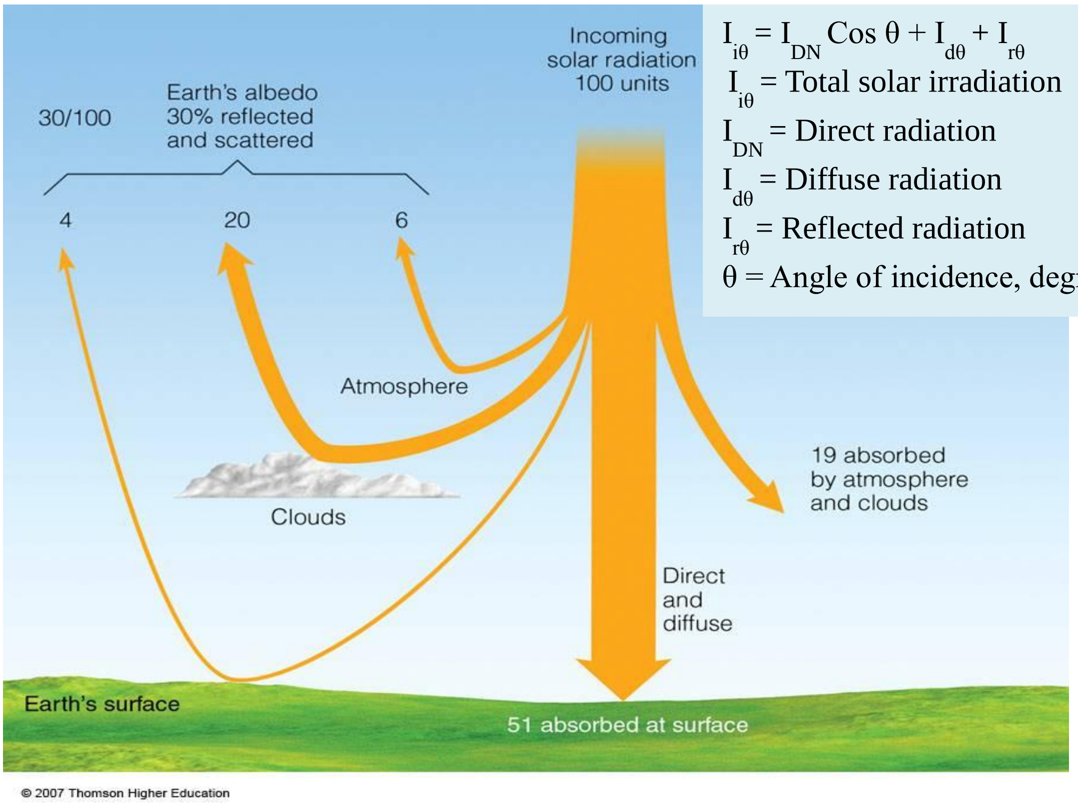
Radiation of the Sun

The sun radiates gargantuan amount of energy into solar system or universe, this energy travels at 3.0 x 108 m/s^2; thus being able to reach the earth's surface within eight minutes. Solar energy is considered renewable because it is constantly available (in the absence of weather conditions like winter, clouds, night, rainfall etc.) and it is replenished naturally.

Due to the rotation of the earth, only half of the earth is lit by sunlight at a time. Solar radiation comes in the form of electromagnetic wave which has wide spectrum. The longer the wavelength of the spectrum, the less energy it has and the shorter the wavelength the more energy it possess. Of all the spectrum of 6 wavelengths of the sun, only wavelength ranging between 0.29µm and 2.3µm reaches the earth's surface. Most of the solar energy which hits the surface of earth is reflected back into space.

Irradiance or insolation is the solar radiation intensity which falls on a surface. This quantity is measured or expressed in watts per meter square (W/m^2).The *global irradiance* is the solar radiation that reaches horizontal surface on the earth through the atmosphere. The following factors account for global irradiance.

Beam radiation (I_b): is the radiation that passes straight through the atmosphere and hits the earth's surface, hits the plane. It is also known as Direct radiation.



$I_{i\theta} = I_{DN} \cos\theta + I_{d\theta} + I_{r\theta}$

$I_{i\theta}$ = Total solar irradiation

I_{DN} = Direct radiation

$I_{d\theta}$ = Diffuse radiation

$I_{r\theta}$ = Reflected radiation

θ = Angle of incidence, degrees

Figure 1.1 Solar radiation passes through the atmospheres *(awdet H.Mohammed*, 2007).

Diffuse radiation (I_d): in diffuse radiation, the solar radiation is scattered in all direction in the atmosphere and part of it arrives at the earth's surface.

Total radiation (I_t): is the sum of the beam and diffuse radiation, sometimes known as *global radiation*.

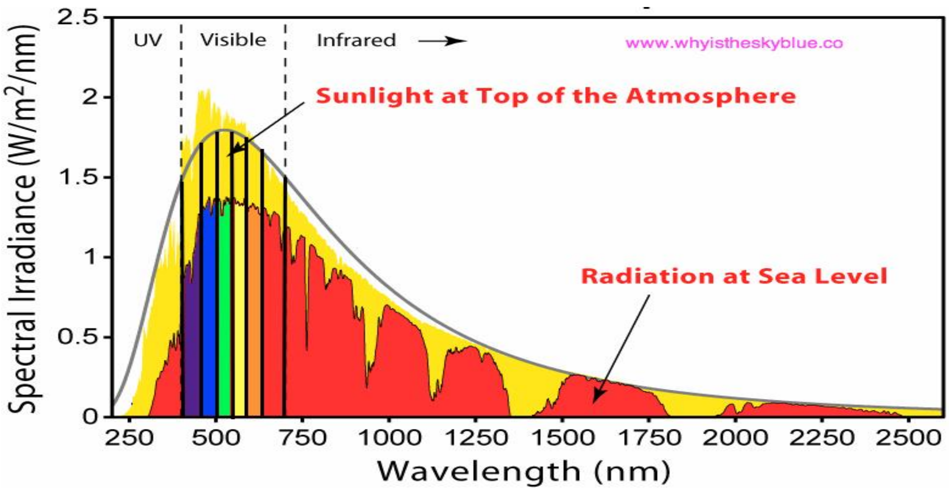


Figure 1.2. Solar radiation spectrum.

Solar potential in Myanmar

Myanmar has a tropical monsoon climate. The cooler, dry season lasts from November to April and the hotter, wet season from May to September or October. The weather is hottest from March-May, before the onset of the heaviest rains.

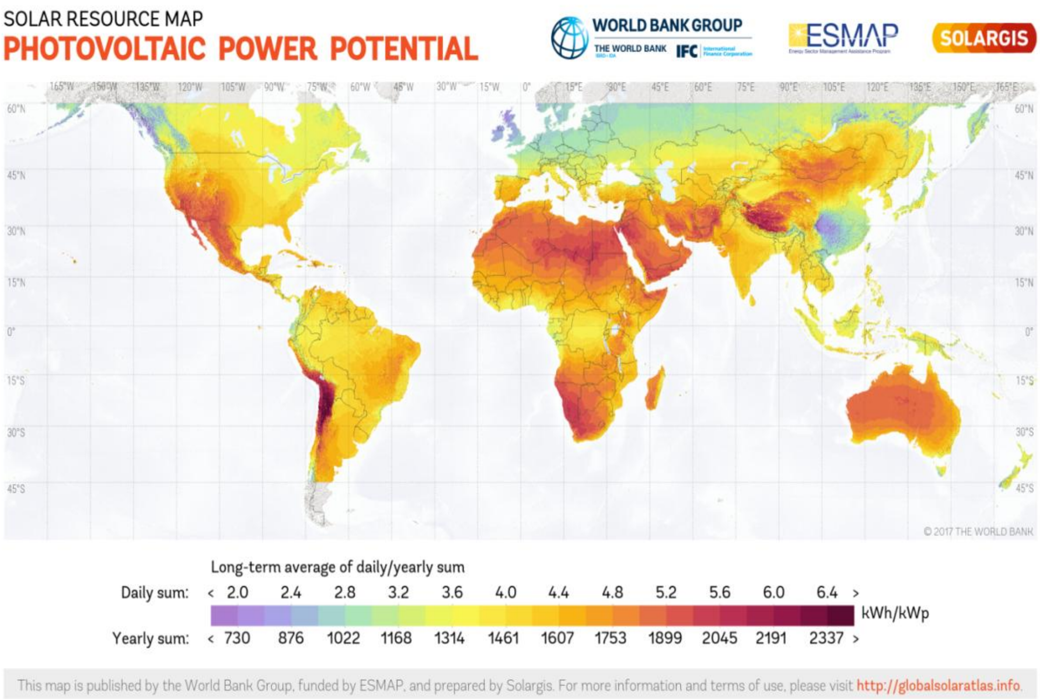


Figure 1.3. Global Photovoltaic Power Potential (World Bank Group, 2016).

The overall potential for solar power is estimated to be 51,973 terawatt-hours per year, with the highest potential in the central dry zones of the country. The former government signed two major solar power deals with foreign investors, both in 2014. US-based ACO Investment Group will invest USD 480 million to build two 150 MW solar plants near Mandalay, both of which are due to enter operation in 2016. Separately, Synergy Business Development Co Ltd (SBD), a local firm, together with its foreign partner have submitted a proposal to construct a

200MW solar power plant Meiktila Township, Mandalay Region to the MOEE, said U Lin Naing Oo, managing director of SBD.

According to the study on solar resources and solar PV potential in Myanmar, conducted by the World Bank, most of the population (75%-85%) lives within a 25-50 km radius of HV power lines, which overall are good premises for developing medium- and large-scale solar projects in the country.

Recently, Myanmar State Counsellor Aung San Suu Kyi is opened the first phase of a solar power plant project, which is the first in Myanmar and one of the biggest solar power plants in Southeast Asia, in Minbu Township, Magway Region on June 27. The first phase of the solar power plant located at a place of 800 acres of land space in Minbu Township, implemented under build-operate-transfer (BOT) system by the Green Earth Power (Myanmar) Company, initially added 40 megawatts (mw) to the national grid.

On completion of the remaining three phases of the four-phase 170 mw installed capacity, the plant would produce 350 million kilowatt-hours (kwh) per annum, distributing electricity to about 210,000 households. The electricity generated from the plant will be added to the national grid and cost around 12.5 cents per unit.

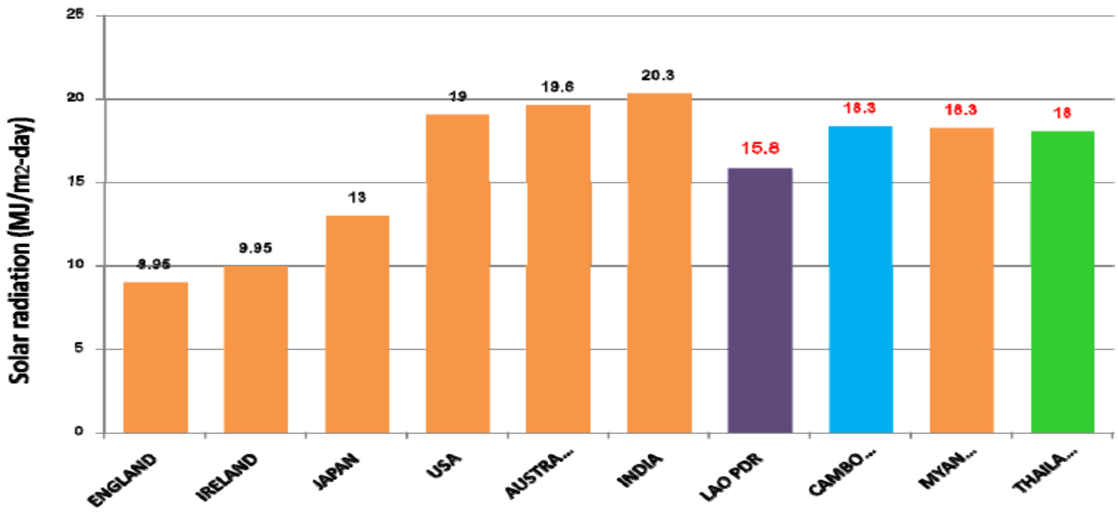


Figure 1.4 Comparison of average daily solar radiation per year (World Bank Group, 2016).

Electricity from the sun which is quite abundant in most of the developing countries is used in rural areas to meet basic electricity needs of a rural community. Today's electricity supply in Myanmar is generated by hydroelectric power plants and fuel generators. However, far from areas which are away from National Grids cannot enjoy the electricity generated by these sources. Since Myanmar is a land of plentiful sunshine, especially in central and southern regions of the country, the first form of energy-solar energy could hopefully become the final solution to its energy supply problem. Sunshine is plentiful during the dry season, averaging 7 to 10 hours a day. During the rainy season the weather is cloudier and daily sunshine amounts average only 3 to 4 hours a day.

Even though most electricity is produced from hydropower in Myanmar, the country has rich technical solar power potential that is the highest in the Greater Mekong sub-region; however, in terms of installed capacity Myanmar lags largely behind Thailand and Vietnam. The country aims to generate 8% of electricity through renewable energy sources-through wind and solar energy-by 2021 and 12% by 2025.

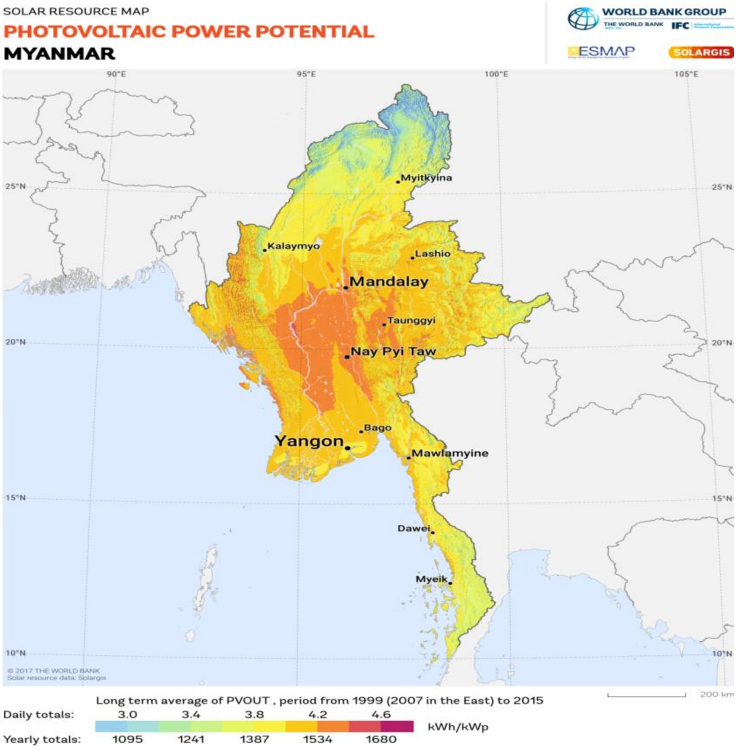


Figure 1.5. PV potential of Myanmar (World Bank Group, 2016).

S. A. Klein method (S. A. Klein, 1976**)**

Using this method we can calculate max output energy from solar incident radiation horizontally. The basic equation of this method :

Declination angle is calculated by the following equation

$$\delta = 23.45 \, sin \, [\, 360 * \frac{(284 + n)}{365}]$$

Where, n represents the day of the year and 1st January is accepted as the start [16, 18, 20, 21].

Incidence angle (θ) is the angle between the radiation falling on the surface directly and the normal of that surface.

$$\theta = cos^{-1} [\cos(\delta).\cos(\emptyset).\ \cos(\omega) + \sin(\delta).\ \sin(\emptyset)]$$

Tilt angle (β) is the angle between the panels and the horizontal plane. This angle is south oriented in the Northern Hemisphere and north oriented in the Southern Hemisphere.

$$\beta = |\emptyset - \delta|$$

Where, φ = $latitude\ angle\ of\ location$

Global formula : E = A * r * H * PR

E = Energy (kWh)

A = Total solar panel Area (m^2)

r = solar panel yield (%)

H = Annual average irradiation on tilted panels

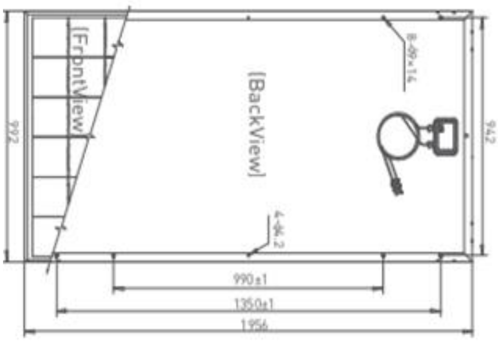
PR = Performance ratio, coefficient for losses

(range between 0.9 and 0.5, default value = 0.75)

Using some specification of Minbu solar power plant in figure 1.6.

Chinese company Jetion Solar has supplied PV modules to Minbu power plant, said to be the first such large-scale project in the country. Recently, an opening ceremony marked the completion of the first phase of electricity generation from Myanmar's first solar power plant, which has been added to the national grid to supplement the country's power needs. Located in Minbu Township, in upper Myanmar's Magwe Region, the Minbu Solar Power Plant was developed by Green Earth Power (Myanmar) under a build-operate-transfer (BOT) contract. It will have a total capacity of 170MW and the first stage complete, the plant is now capable of producing up to 40 MW of power.

STC		Electrical Characteristics									
Tape		JT305PAg	JT310PAg	JT315PAg	JT320PAg	JT325PAg	JT330PAg	JT335PAg	JT340PAg	JT345PAg	JT350PAg
Module Power Range	(W)	305≤Pm<310	310≤Pm<315	315≤Pm<320	320≤Pm<325	325≤Pm<330	330≤Pm<335	335≤Pm<340	340≤Pm<345	345≤Pm<350	350≤Pm
Max-Power	Pm(W)	305	310	315	320	325	330	335	340	345	350
Max-Power Voltage	Vm(V)	36.5	36.6	36.7	36.9	37.1	37.3	37.5	37.7	37.9	38.2
Max-Power Current	Im(A)	8.40	8.51	8.63	8.72	8.81	8.89	8.97	9.06	9.13	9.19
Open-Circuit Voltage	Voc(V)	45.0	45.1	45.2	45.4	45.6	45.7	45.9	46.1	46.3	46.6
Short-Circuit Current	Isc(A)	8.96	9.05	9.14	9.23	9.27	9.35	9.42	9.50	9.57	9.63
Module Efficiency	(%)	15.7	16.0	16.2	16.5	16.7	17.0	17.3	17.5	17.8	18.0
Pm Temperature Coefficients	(%/°C)	-0.41									
Voc Temperature Coefficients	(%/°C)	-0.31									
Isc Temperature Coefficients	(%/°C)	0.05									
Class AAA solar simulator (IEC 60904-4), power or current measurement uncertainty is within ±3%,voltage is within ±2%.											



Varied Irradiation Efficiencies

Irradiance(W/m2)	200	400	600	800	1000
Efficiency (%)	16.7	17.1	17.3	17.4	17.3

Figure 1.6 Specification of solar panel (JT310) of Minbu solar power plant.

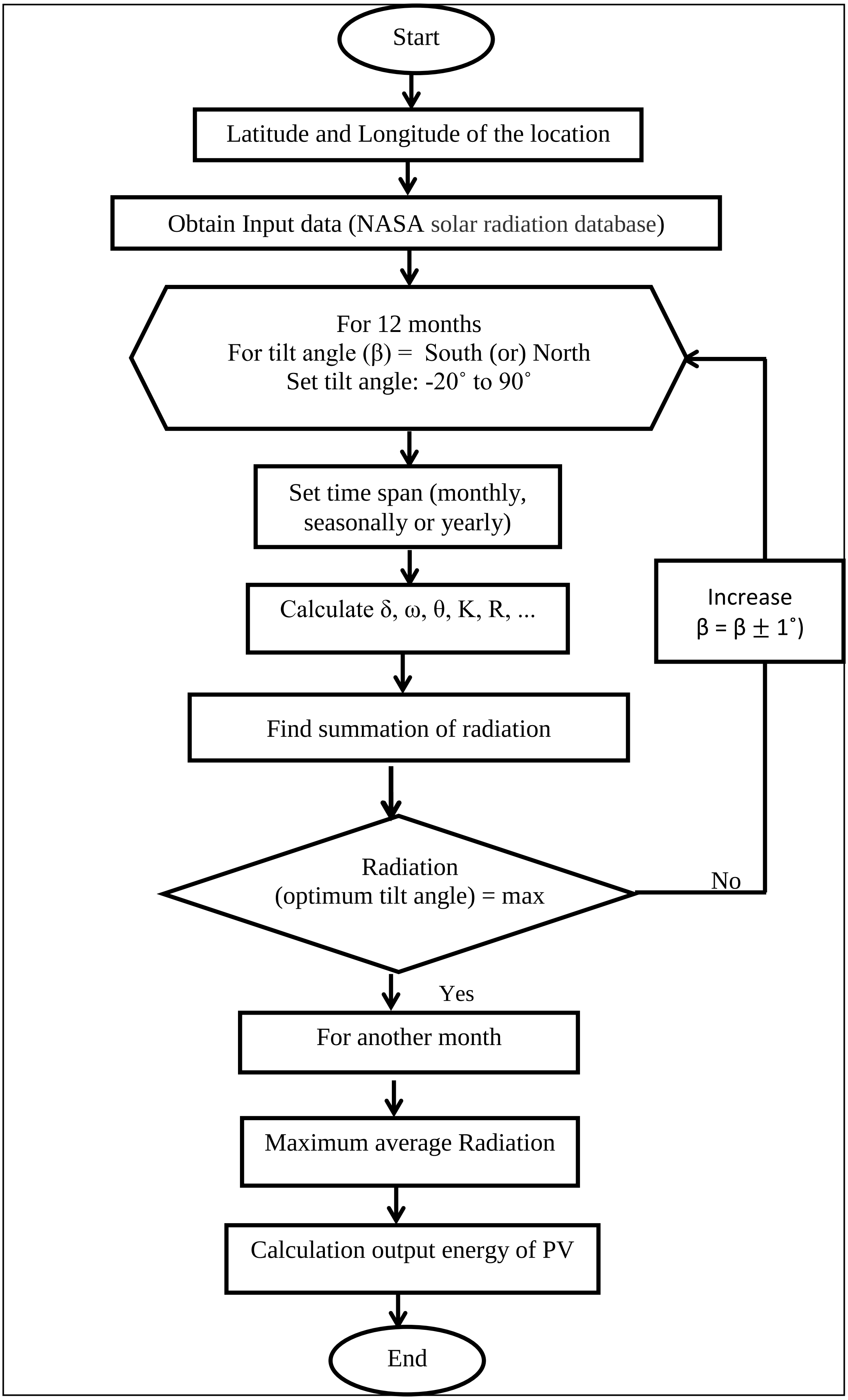


Figure 1.7 Optimization algorithm for PV panels tilt angle.

Calculation model are created for optimization of the tilt angle

In this research, obtaining geometry information from National Aeronautics and Space Administration (NASA) surface meteorology and solar energy - available tables over 22-year average. In this paper proposes an algorithm to calculate the optimum tilt angle of solar panels method was developed by S. A. Klein by using NASA Radiation Data Base.

Figure 1.7. is showing algorithm for the determination of the optimum tilt and orientation of a solar panel using a calculation model based on the orientation of a generic surface with respect to the position of the sun in the sky.

Several simplified design procedures for solar energy systems require monthly average meteorological data. In this paper proposes an algorithm to calculate the optimum tilt angle of solar panels method was developed by S. A. Klein by using NASA Solar Radiation Data Base, consisting of solar radiation and meteorological data all over the world for 22 years period. Figure 1.8 (a) and (b) showing Input data for calculation model for optimum tilt angle for Minbu solar power plant.

№	Region	Station	φ	ψ	Month												Yr
			Location		1	2	3	4	5	6	7	8	9	10	11	12	
1	Ma Gway	Min Bu	20.18	94.87	159.34	160.2	192.8	189.9	168.02	118.5	123.1	121.21	127.5	135.8	128	142	1766
			Solar radiation data from NASA														
					5.14	5.72	6.22	6.33	5.42	3.95	3.97	3.91	4.25	4.38	4.3	4.6	
Среднемесячный дневной приход солнечной радиации на горизонтальную площадку за пределами земной атмосферы Эг0 (кВт*ч/м2*сут)																	
		месяц	1	2	3	4	5	6	7	8	9	10	11	12			
		n	17	47	75	105	135	162	198	226	258	288	318	344			
Input data		ф	Среднемесячный суточный приход солнечной радиации на за пределами земной атмосферы Э0сут (кВт*ч/м2*сут)														
		20.18	7.45	8.51	9.69	10.5	10.9	11	10.9	10.6	9.92	8.84	7.7	7.09			
		Days of month	31	28	31	30	31	30	31	31	30	31	30	31			
		ρ	0.13	0.13	0.14	0.15	0.15	0.18	0.18	0.18	0.17	0.15	0.15	0.14	0.15		

Figure 1.8 (a) . Input data for optimum tilt angle by using Klein method.

		β	cos (ф-β)	sin(ф-β)	tgф	cosф	sinф		tg(ф-β)							
		25	0.996	-0.084	0.367	0.94	0.345		-0.084							
		28	n	δ	cosδ	sinδ	ωr	ω'	ωβ	sinωr	sinωβ	A	B	C	D	Kпр
				градус	o.e	o.e	градус	градус	градус	o.e	o.e.	o.e.	o.e.	o.e.	o.e.	o.e.
Optimum angle		1	17	-20.94	0.93	-0.36	81.97	91.90	81.97	0.99	0.99	0.92	0.04	0.87	-0.18	**1.39**
		2	47	-13.01	0.97	-0.23	85.18	91.16	85.18	1.00	1.00	0.97	0.03	0.91	-0.12	**1.25**
4.839425		3	75	-2.49	1.00	-0.04	89.13	90.26	89.13	1.00	1.00	1.00	0.01	0.94	-0.02	**1.09**
		4	105	9.34	0.99	0.16	93.51	89.25	89.25	1.00	1.00	0.98	-0.02	0.92	0.09	**0.95**
		5	135	18.74	0.95	0.32	97.20	88.41	88.41	0.99	1.00	0.94	-0.04	0.88	0.19	**0.84**
		6	162	23.07	0.92	0.39	99.04	87.99	87.99	0.99	1.00	0.92	-0.05	0.85	0.23	**0.80**
		7	198	21.23	0.93	0.36	98.25	88.17	88.17	0.99	1.00	0.93	-0.05	0.87	0.21	**0.82**
		8	226	14.19	0.97	0.25	95.37	88.82	88.82	1.00	1.00	0.97	-0.03	0.91	0.14	**0.89**
		9	258	2.33	1.00	0.04	90.90	89.85	89.85	1.00	1.00	1.00	-0.01	0.94	0.02	**1.03**
		10	288	-9.49	0.99	-0.16	86.53	90.85	86.53	1.00	1.00	0.98	0.02	0.92	-0.09	**1.20**
		11	318	-18.84	0.95	-0.32	82.85	91.70	82.85	0.99	0.99	0.94	0.04	0.88	-0.16	**1.35**
		12	344	-23.03	0.92	-0.39	81.07	92.10	81.07	0.99	0.99	0.91	0.05	0.85	-0.19	**1.44**

Figure 1.8 (b). Calculation model for optimum tilt angle of PV panels.

The results of output energy as shown in figure 1.9 - 1.14.

	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB
1		cosβ	F=(1+cosβ)/2	D=(1-cosβ)/2													
2		0.9064	0.9532	0.0468												Output energy	
3		Month	Days of month	Эгмес	Эгсут	Эг о сут	Ко	Эгд	1-Кд	Кпр	(1-Кд)*Кпр	Кд*F	ρ	Кβ	Эβсут	Эβмес	Эβгод
4				кВт*ч/м2*мес	кВт*ч/м2*сут	кВт*ч/м2	о.е	кВт*ч/м2	о.е.	о.е.	о.е.	о.е.	о.е.	о.е.	кВт*ч/м2*сут	кВт*ч/м2*мес	кВт*ч/м2
5		1	31	159.34	5.14	7.45	0.69	0.940	0.817	1.39	1.139	0.174	0.13	1.32	6.78	210.21	
6		2	28	160.16	5.72	8.51	0.67	1.210	0.788	1.25	0.986	0.202	0.13	1.19	6.83	191.19	
7		3	31	192.82	6.22	9.69	0.64	1.600	0.743	1.09	0.813	0.245	0.14	1.06	6.62	205.33	
8		4	30	189.90	6.33	10.5	0.60	2.010	0.682	0.95	0.646	0.303	0.15	0.96	6.05	181.54	
9		5	31	168.02	5.42	10.9	0.50	2.410	0.555	0.84	0.468	0.424	0.15	0.90	4.87	151.04	
10		6	30	118.50	3.95	11	0.36	2.390	0.395	0.80	0.315	0.577	0.18	0.90	3.55	106.64	1895.26
11		7	31	123.07	3.97	10.9	0.36	2.390	0.398	0.82	0.325	0.574	0.18	0.91	3.60	111.65	
12		8	31	121.21	3.91	10.6	0.37	2.300	0.412	0.89	0.367	0.561	0.18	0.94	3.66	113.52	
13		9	30	127.50	4.25	9.92	0.43	2.130	0.499	1.03	0.515	0.478	0.17	1.00	4.25	127.53	
14		10	31	135.78	4.38	8.84	0.50	1.790	0.591	1.20	0.707	0.390	0.15	1.10	4.83	149.80	
15		11	30	127.80	4.26	7.7	0.55	1.410	0.669	1.35	0.905	0.315	0.15	1.23	5.23	156.88	
16		12	31	142.29	4.59	7.09	0.65	1.030	0.776	1.44	1.114	0.214	0.14	1.33	6.13	189.94	
17				1766.39	4.85												

Figure 1.9 The results of output energy.

In my calculation, there are three types of optimum tilt angle for Minbu Solar power plant. They are : fixed-tilt angle, seasonally tilt angle and monthly tilt angle. Optimum fixed-tilt angle means you install your solar panels angle is all the time and you can not change the angle of solar panels. Seasonally optimum tilt angle means you can change your angle of solar panels in each season. Finally, monthly optimum tilt angle means you can change the angle of solar panels in each month.

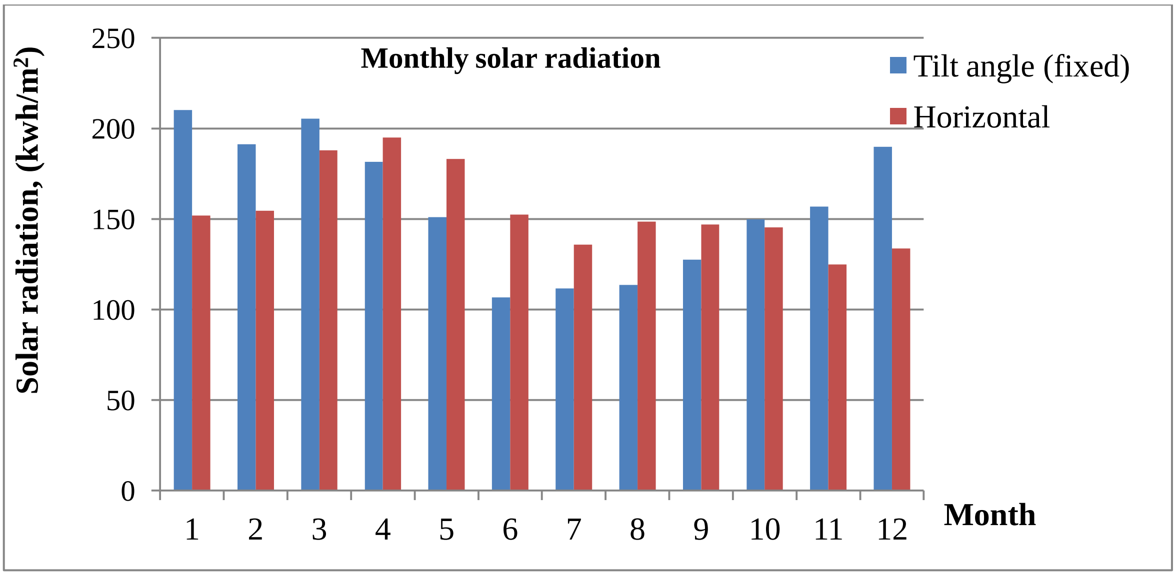


Figure 1.10 (a) Solar radiation for optimum tilt angle for Minbu solar power plant.

Total output solar radiation for horizontal (0˚) – 1860 kwh/m^2 and total output solar radiation for tilt angle (25˚) – 1895 kwh/m^2 respectively.

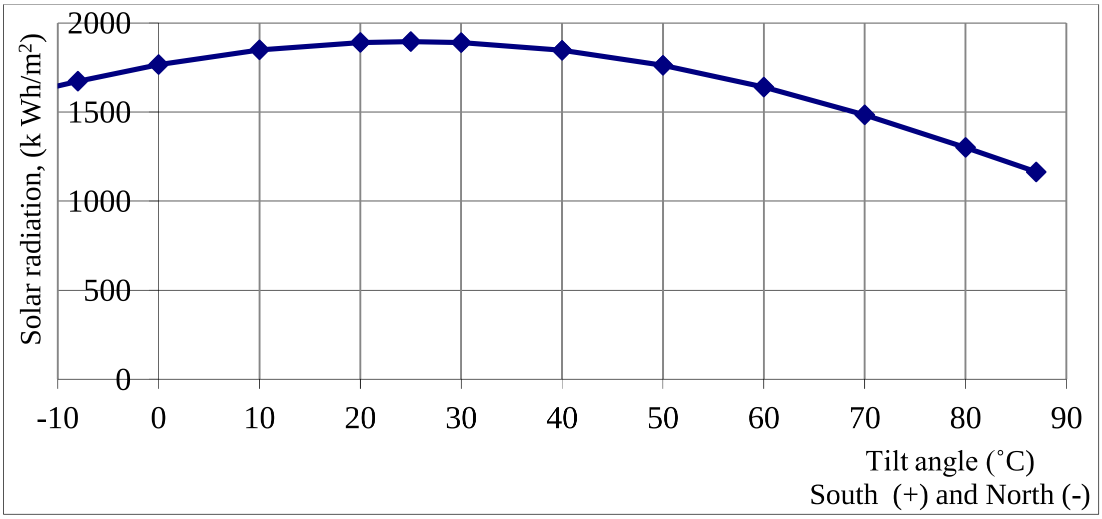


Figure 1.10 (b). Determination of the optimum fixed tilt angle for Minbu solar power plant.

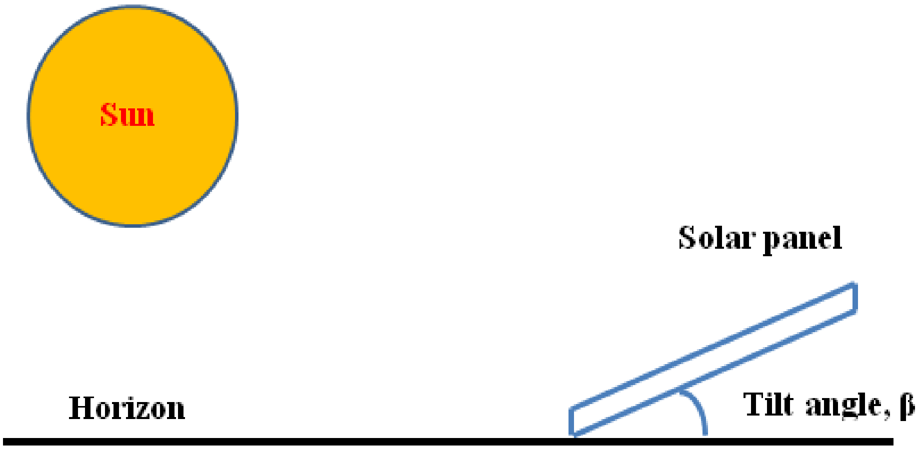


Figure 1.10 (c) Example optimum fixed tilt angle for Minbu solar power plant.

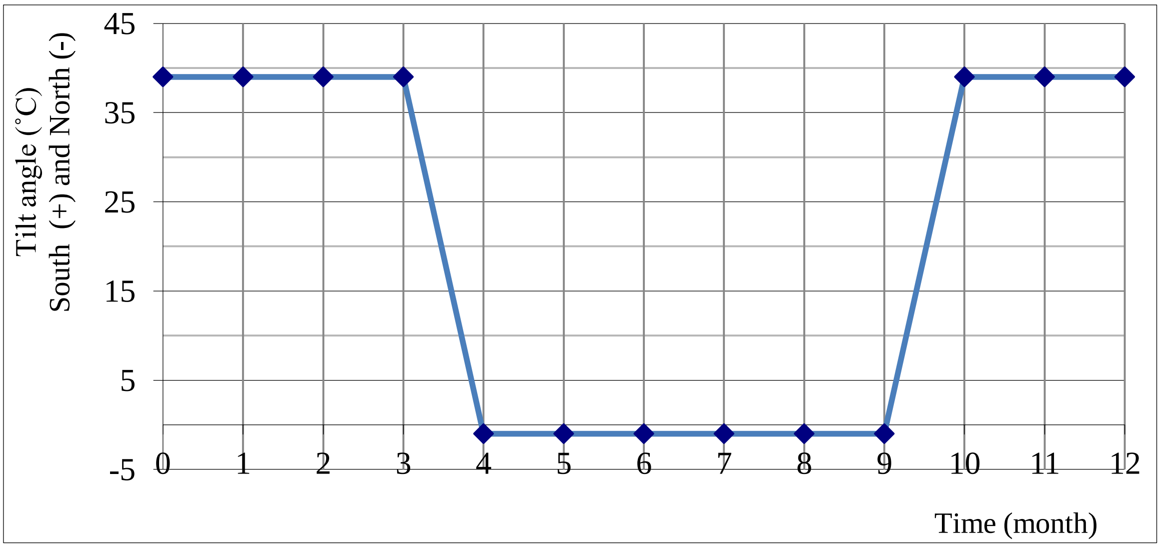


Figure 1.11 Determination of seasonally optimum tilt angle for Minbu solar power plant.

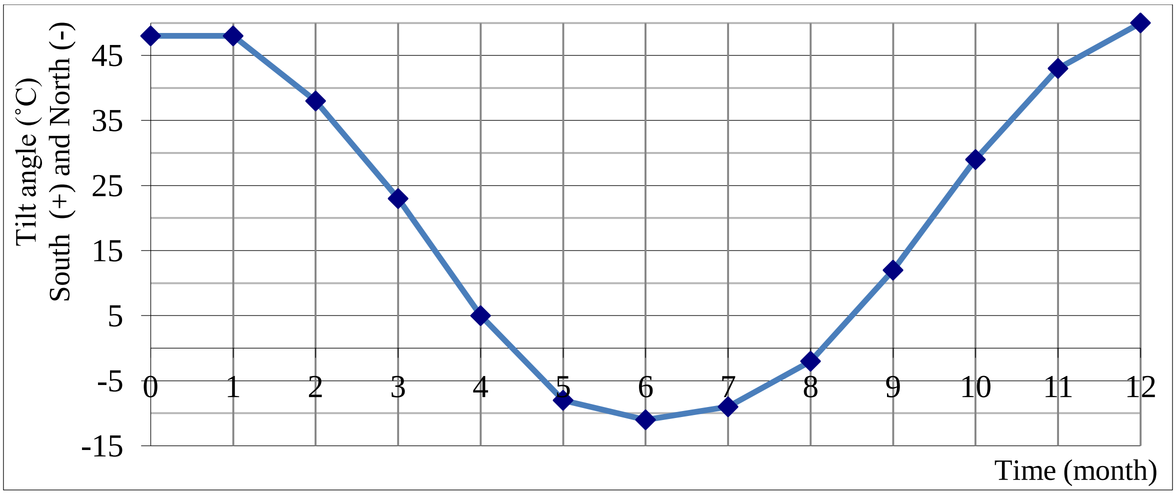


Figure 1.12 Determination of monthly optimum tilt angle for Minbu solar power plant

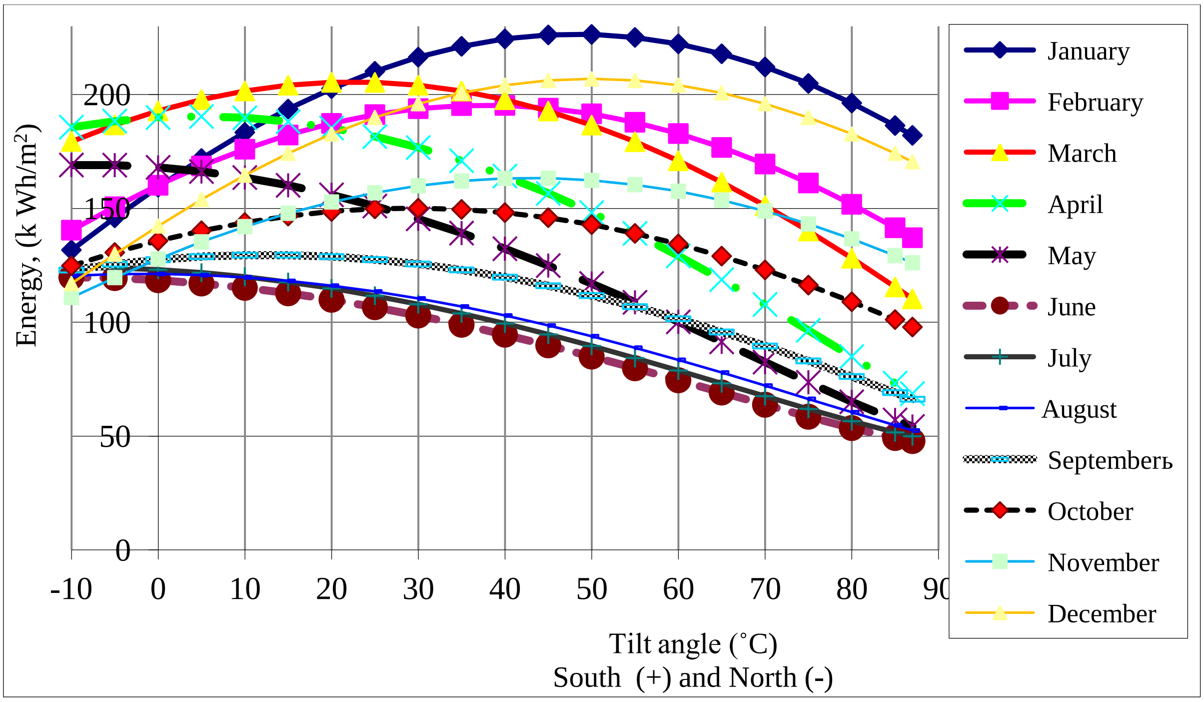


Figure 1.13 Monthly tilt angle optimization results (solar radiation and tilt angle) for Minbu solar power plant

For Minbu 170 MW solar power plant, the total number of PV modules are 548387.

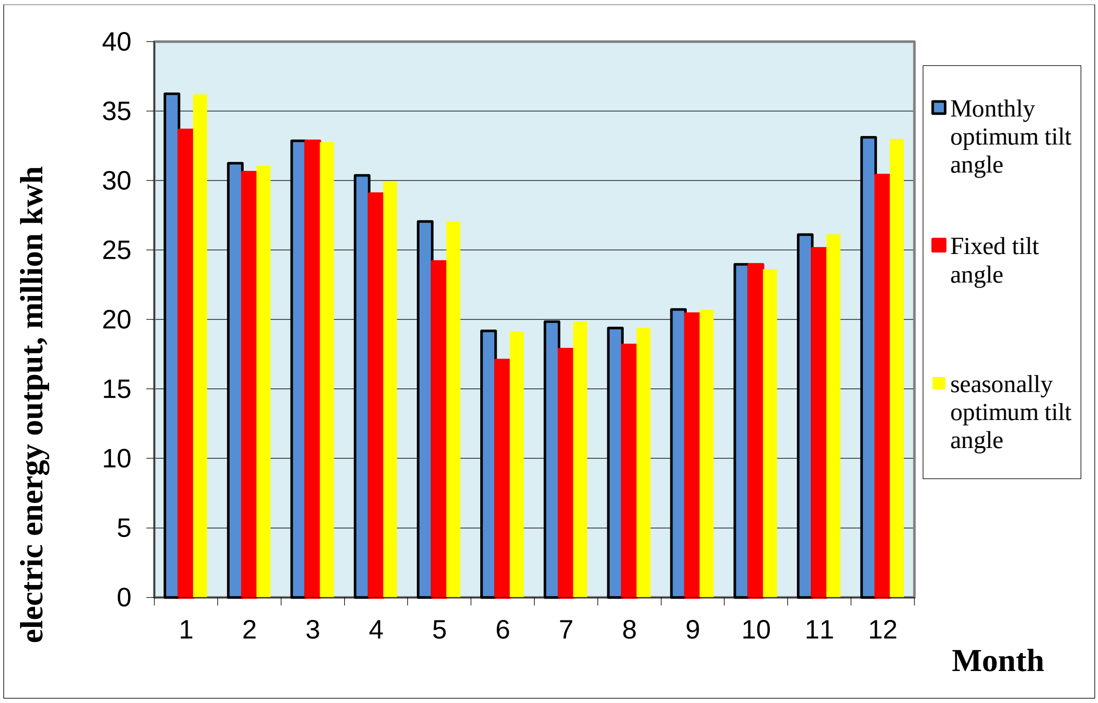


Figure 1.14. Output energy for Minbu solar power plant (fixed, seasonally and monthly optimum tilt angle)

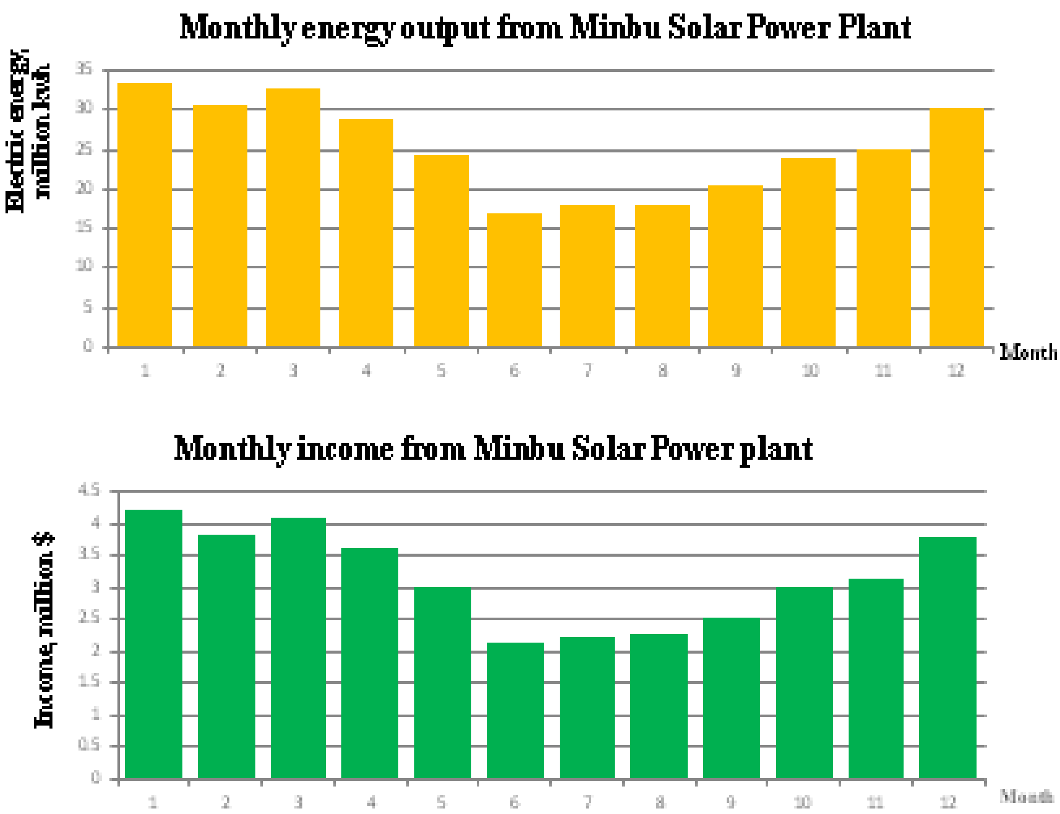


Figure 1.15 Energy output and income of Minbu Solar Power Plant (170 MW).

Conclusion

Myanmar is a land of plentiful sunshine, especially in central part of Myanmar. In research, proposed method we can calculate for output energy for various optimum tilt angle using Klein method. S. A. Klein method is very suitable for some regions which is near equator. From an economic point of view, the optimum tilt angle for Minbu solar power plant is β = 25˚ (fixed). Electricity tariff 12.5 cents is expensive for Myanmar. For example, Vietnam – 9.3 cents and Combodia - 9.1 cents. Minbu Solar power plant will generate electric output energy more than 300 million kwh and will receive income around 37 million $ per year. This calculation model will help how to determination of the optimum tilt angle and orientation of a solar panel any location of Myanmar. According to the results, economically the best optimum tilt angle for Minbu solar power plant β = 25˚. This solar power plant will generated solar energy about 302.5 million kWh per year.

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