Development of a New Program for Design and Analysis of PV Hybrid System for Target Area in Thailand

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***Abstract*— *This paper presents the development of a new software program for the Design and Analysis the PV-Hybrid system for Thailand that never published anywhere before. The Utility of this software is finding of sizing and categorizing of optimal system in target area of Thailand. In this paper, we use hourly simulation technique methods. The first step in sizing, the long term duration of sunshine data recorded for five years are used to calculate the daily mean maximum duration sunshine in a year. These data are used to estimate the global radiation on horizontal surface from linear relation in Angstrom equation. Next, the calculated radiation data is used as initial input to systems. Finally, we solve sizing of PV hybrid system by linear programming model. The reliability level is measured in term of loss of load probability (LOLP).*

***Keywords*— Design PV hybrid system, analysis software.**

1. INTRODUCTION

The important of designing the PV-hybrid system is the reliability. The reliability depends on sizing and constructing of the PV hybrid system which must be appropriated for the load demand with more solar fraction. The method [1] demonstrates to analysis of the sizing system and relation of the reliability level by compared between the averages of solar energy with the average of load demand from statistic of many station nearly at the site location. The method is easy to calculate the size but not attended the changing value of solar energy and solar is the direct effect to the ability of power distribution. To create the map of co-efficiency for calculation of system size is difficult. Then the average of solar energy are developed in afterwards [2] which easier than the statistic of solar energy but this method has to make the mathematic model for analysis of sizing and the reliability level of system. The method is reproducing the duration.

From mentioned methods, they are difficult to calculate the sizing system. It needs expertness and the average of statistic of solar energy for sizing analysis. The sizing result of the mentioned methods is sometime smaller than would be. Therefore, this paper proposes a new development program for design and analysis of the PV-hybrid system for target area in Thailand using Matlab. The paper will show the result case study PV-hybrid system for the site-location at Phathumthani province, Thailand. The province locates at latitude 14.20°N and longitude 100.34°E. From the implementation of new program, the sizing is correctly calculated and the graph analysis is created, moreover, the calculation time is also fast.

2. BESIC CONCEPT THEORY

2.1 Irradiation on horizontal surface

In clear sky, the irradiation depends on the distance between the earth and the sun with according to the angle between direction of horizontal solar and density of steam [3]. Equation (1) is used for calculation the total intensity of irradiation and equation (2) is for calculate the intensity of direction irradiation.

$$Gc = F \sum_{i=0}^{6} ai \left[\frac{z}{90} \right]^{2i} \tag{1}$$

$$Ic = F \sum_{i=0}^{6} bi \left[\frac{z}{90} \right]^{2i} \tag{2}$$

when: G_c is Intensity of horizontal irradiation in clear sky

I_c is Intensity of direction horizontal irradiation in clear sky

a_i, b_i is Co-efficiently

and $$F = 1 - 0.0335 \sin \frac{[360\,(D-94)]}{365} \tag{3}$$

$$Z = \cos^{-1}(\sin L \sin \delta + \cos L \cos \delta \cos \hbar) \tag{4}$$

$$\delta = 23.45 \sin\left(\frac{360}{365}(284 + D)\right) \tag{5}$$

Hour angle (*h*) depended on solar time and Longitude of the location of station find out in (6), (7), (8), (9):

$$\text{Before noon } (h) = 15\,(solar\ time - 12) \tag{6}$$

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After noon (h) = 15 (1*solar time* + 12) (7)

By: *Solar time* = $\text{LST} \pm 4(\text{Lo(std)} - \text{Lo(local)}) + \text{EOT}$ (8)

$$EOT = 9.87\sin\left[2\left[\frac{360}{364}(D-81)\right]\right] - 7.5\cos\left[\frac{360}{364}(D-81)\right] - 1.5\sin\left[\frac{360}{364}(D-81)\right] \quad (9)$$

when: *LST* is Local Standard Time
$L_{o(std)}$ is latitude of the country
$L_{o(local)}$ is longitude of the country
EOT is Equation of Time

The intensity of diffuse irradiation in clear sky for calculate by equation (10)

$$Dc = Gc - Ic\cos(z) \quad (10)$$

2.2 Irradiation on tilt angle

The irradiation on tilt angle is included the reflected irradiation. The quantity of the irradiation depends on climate at the site location. The value of direct irradiation factor (RB) is at location in north part which the face of the PV-panel set to south.

$$R_B = \left(\frac{\cos i}{\cos z}\right) \quad (11)$$

$$= \frac{\cos(l-\beta)\cos\sigma\cos\hbar + \sin(L-\beta)\sin\sigma}{\cos L\cos\sigma\cos\hbar + \sin L\sin\sigma} \quad (12)$$

when: L is Longitude of location
δ is Angle between sun with equator (- 23.45 °S + 23.45 °N)
h is angle hour of sun (-180° to + 180°)
B is Angle between horizontal surfaces with Tilt angle

The intensity of diffuse radiation will be calculated by equation (13). The parts of the tilt angle radiation calculate from radiation reflected from earth, which co-efficiency of reflects is (ρg). Then the calculation of irradiation intensity (G_p) from equation (13) is:

$$D(\beta) = (Ic + Dc)\rho g\left[\frac{1+\cos\beta}{2}\right] \quad (13)$$

$$Gc = (Ic + Dc)\rho g\left[\frac{1-\cos\beta}{2}\right] \quad (14)$$

Then the total of irradiation can be calculated from equation below:

$$G\beta = IcR_B + Dc\left[\frac{1+\cos\beta}{2}\right] + (Ic+Dc)\rho g\left[\frac{1-\cos\beta}{2}\right] \quad (15)$$

2.3 Radiation at cloudy sky

The irradiation is absorbed by steam and medium in climate and can be measured by Clearness Index (k_d). The (k_d) is the ratio between total irradiation in cloudy sky with the total irradiation on clear sky show in equation 16.

$$Kd = \frac{G_D}{G_i} \quad (16)$$

$$D_D = G_D - I_D\cos z \quad (17)$$

$$I_D = \frac{(1-r_d)}{\cos z}G_D \quad (18)$$

when: G_D is Horizontal Irradiation in cloud sky
r_d is The ratio between diffuse solar radiation with total solar radiation in cloud sky
D_D is Horizontal diffuse solar radiation in Cloud sky
I_D is Horizontal direct solar radiation in cloud Sky

To apply for calculation of the total tilt irradiation in cloud sky [4], we can abtain as in equation 19.

$$G(\beta) = \frac{(G_D - D_D)}{\cos z}\cos\psi$$
$$D_D\left[\frac{1+\cos\beta}{2}\right]\left[1+\left[1-\left[\frac{D_D}{G_D}\right]^2\right]\sin^2\left[\frac{\beta}{2}\right]\right]$$
$$\left[1+\left[1-\left[\frac{D_D}{G_D}\right]^2\right]\cos^2\psi\sin^2 z\right] \quad (19)$$

$$\psi = \cos^{-1}\left(\cos(L-\beta)\cos\sigma\cos\hbar + \sin(L-\beta)\sin\sigma\right)$$

when: $G(\beta)$ is Total irradiation in tilt angle.

2.4 Relationship between irradiation with long term duration of sunshine

The long term duration of sunshine is practically used to predict the solar energy by relation of the linear Armstrong equation shown as equation 20.

$$\frac{G}{G_c} = a + b\left[\frac{s}{S_d}\right] \quad (20)$$

$$S_d = \frac{2}{15}\cos^{-1}(-\tan L\tan\sigma) \quad (21)$$

$$a = 0.2296 + 0.0049L \quad (22)$$

$$b = 0.5709 + 0.0125L \quad (23)$$

when: G is Horizontal solar energy
G_o is Atmosphere solar radiation

S is Maximum of number of hour duration of sunshine from the measurement data
S_d is Number of hour of duration of sunshine from calculate
S_m is maximum of duration of sunshine
a, b is Co-efficiency [5]

2.5 Power out of solar panel

The electrical power output of the Photovoltaic panel can be calculated by equation followings.

$$\Delta I_{PV} = \alpha\left[\frac{G_\beta}{G_{ref}}\right]\Delta T_{ref} + \left[\frac{G_\beta}{G_{ref}} - 1\right] \quad (24)$$

$$\Delta V_{PV} = -v\Delta T_{ref} - R_s \Delta I_{PV} \quad (25)$$

$$I_{PV} = I_{sc} + \Delta I_{PV} \quad (26)$$

$$V_{PV} = V_{ref} + \Delta V_{PV} \quad (27)$$

The hourly electric power produced by Photovoltaic is calculated by equation 28.

$$W_{PV} = \int_{ti}^{tj} \left(V_{PV}(t) I_{PV}(t)\right) dt \quad (28)$$

when:
I_{pv} is Photovoltaic current
Isc is Short circuit current
I_{ref} is Reference of current
V_{pv} is out put voltage
V_{ref} is Reference of voltage
Wpv is Power out put
Rs is Series resistance in photo cell
α is Current Co-efficiency
v is Voltage Co-efficiency

2.6 Temperature of solar cell modeling

The intensity of radiation dependes on the temperature of the solar panel is shown in equation 29.

$$\mathrm{Tc} = \mathrm{T} + (0.02)\mathrm{G}\beta \quad (29)$$

$$\Delta \mathrm{T} = \mathrm{T_C} - \mathrm{T_{ref}} \quad (30)$$

when:
T is ambient temperature
Tc is Solar cell temperature
$Tref$ is Solar cell temperature reference

2.7 Lead-acid battery modeling

As the Lead Acid Battery is normally used for the PV hybrid system, therefore the battery is considered for this study. The state of charge (SOC) of battery can be calculated by equation 31.

$$\mathrm{SOC(i)} = \mathrm{soc(i-1)} + \eta_{ch}\left[\frac{Ah^G(i) - Ah^C(i)}{C_{cef}}\right] \quad (31)$$

$$Vb = (Vb\_end)(NC) + ((Vb\_over - Vb\_end)(SOC)(NC)) \quad (32)$$

$$Wb_{ch} = Ah^G(Vb.Ns) \quad (33)$$

$$Wb_{dis} = Ah^C(Vb.Ns) \quad (34)$$

when:
Ah^G is hourly charging current
Ah^C is Hourly Discharging current
ηch is Efficiency of charge
C_{cef} is Battery capacity
Vb is Terminal voltage
Vb_end is End of voltage
Vb_over is Maximum voltage
Nc is Number of Cell
Wb_{ch} is Battery power
Wb_{dis} is Battery discharge power

3. STEP OF THE PROGRAM

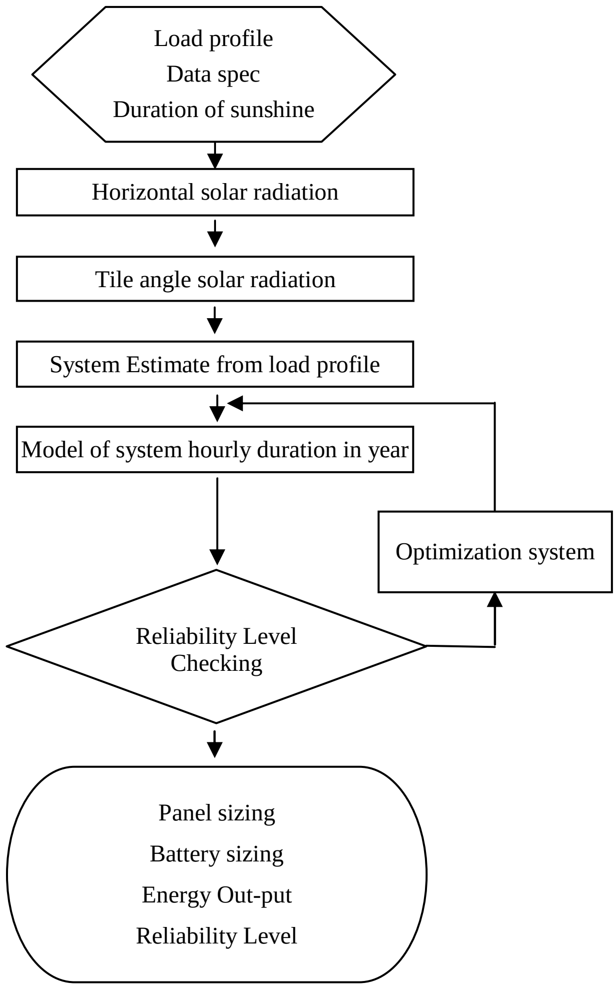

Fig. 1. Program analysis diagram.

There are 6 steps of program analysis which can be described as:

Step 1: The model of horizontal solar irradiation in clear sky, Firstly program will calculate the total solar radiation from equation (1) and then calculate direct solar radiation from equation (2), finally, program will find out of diffuse solar radiation by equation (10).

Step 2: The model of tilt angle solar radiation, the program will estimate of the clearness factor *(kd)* from equation (20) and equation (35). The duration of sunshine is the average of data record in 5 years but must minus by 0.4 hr before bring data to the equation (37), (38).

$$Kd = a + b\left[\frac{S}{S_d}\right] \qquad (35)$$

$$S = \sum_{n=1}^{5}\left[\frac{S_m}{n}\right] \qquad (36)$$

As in the morning, the atmosphere has more steam, this affects to the calculation. Then the coefficient *a, b*, vary by the latitude of location which calculated by equation (22), (23), (37) and (38).

$$Si = \frac{2}{15}\cos^{-1}(-\tan L \tan \delta),\ i\ldots 1, 2, 3 \qquad (37)$$

and: $$Sm = \sum_{n=1}^{m}\left[\frac{Si}{m}\right];\ m\ldots.. 1,2,3 \qquad (38)$$

Step 3: The estimate solar energy in hourly is used to determine the first value of sizing system as following equations.

$$PV\,modulesize = \frac{\dfrac{\left[\sum_{i=1}^{365} Wl_{daily}(i)\right]}{365}}{\dfrac{\left[\sum_{i=1}^{365} Wm_{daily}(i)\right]}{365}}(V_{ref}, I_{ref}) \qquad (39)$$

$$N_B = \frac{\dfrac{\left[\sum_{i=1}^{365} Wl_{night}(i)\right]}{365}}{[C_{10}.Vb]} \qquad (40)$$

$$BatterySize = N_B C_{10} \qquad (41)$$

when: WL_{daily} is Daily load

WL_{night} is Night load (18.00-06.00)

Wm_{daily} is Power output of Solar panel

N_B is Number of Battery

V_{ref} is Reference of solar cell voltage

I_{ref} is Reference of solar panel current

Step 4: The simulation is started by comparing the power produced by PV and load profile by chart in Fig.2.

Case 1: If the power output of PV is more than load, the surplus energy is charged to battery (PV-Battery system). If the energy has more which can not be used then set to be the Excess Energy.

Case 2: The power output of PV less than load demand, the energy is not sufficient; the battery will discharge to load. If power battery storage is not sufficient that means the Energy deficit or Unmet Load.

Case 3: The power output of PV to be equal to power of load is then energy balance.

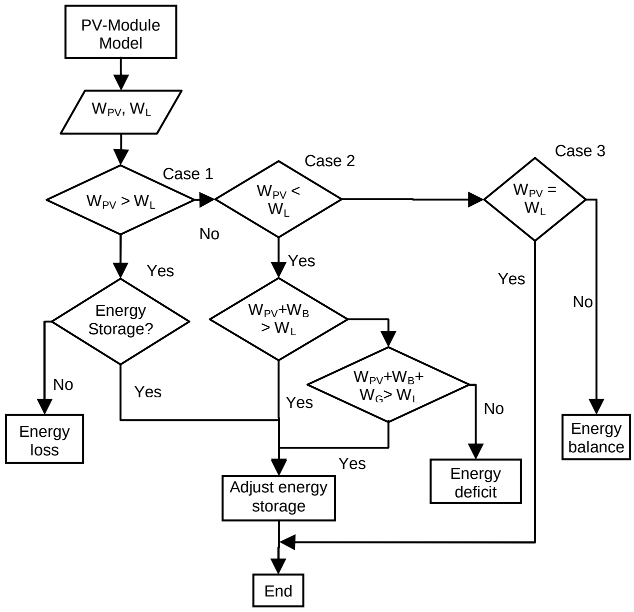

Fig. 2. System analysis diagram.

Step 5: Analysis of sizing and construction of system by using the linear equation program in MATLAB.

$$Min_x\ f^T(x) \qquad Ax \le b \qquad (42)$$
$$Aeq = beq$$
$$lb \le x \le ub$$

$$x = linprog(f, A, b, Aeq, beq, lb, ub) \qquad (43)$$

when: *f* is Object Function

A is Inequality Constraint

Aeq is Equality Constraint

b, beq is Vector

lb, ub is boundary lower and above

Step 6: Increase and decrease of sizing system by receiving "*x*" from last step and confirm to the reliability level following equation (44).

$$LOLP = \frac{\sum(EnergyDeficit)}{\sum(EnergyLoad)} \qquad (44)$$

4. PRPGRAM AND EXPERIMENTATION

From the proved equations, a new software program for PV hybrid design can be developed. The MATLAB software including GUI is selected for the program. The feature of software is shown as in Figure 3. The software is easily used under MATLAB environment. The user can just have a typical installation of MATLAB and then using the new software as a tool in MATLAB. The program is a graphic interface program. The user can input load profile, select the system type, location in Thailand, and then jut click a CALCULATION button, the results will carry out all necessary information such as sizing of PV, battery and all components. The program also calculates and provides the solar radiation at the location. The program provides very powerful analysis tool. The user can check the results to investigate the analysis in order to make the decision. The analysis shows both graphic and data table. Figure 3 shows the system design and analysis of an example experiment of a PV-battery system.

The experimental results are demonstrated; firstly, in table 1, the result shows the comparative monitoring and simulation of horizontal solar radiation at different provinces in Thailand. From the table 1, the comparison has some error however the error is very low so that the results are acceptable, the maximum average error is only 2.8%.

To experiment the program design, the selected load profile as shown in Fig.4 is selected for the design. The system type is PV-Battery system. The program provides PV modules and other component information from industry production data sheet as in table 2 which user can freely select for design.

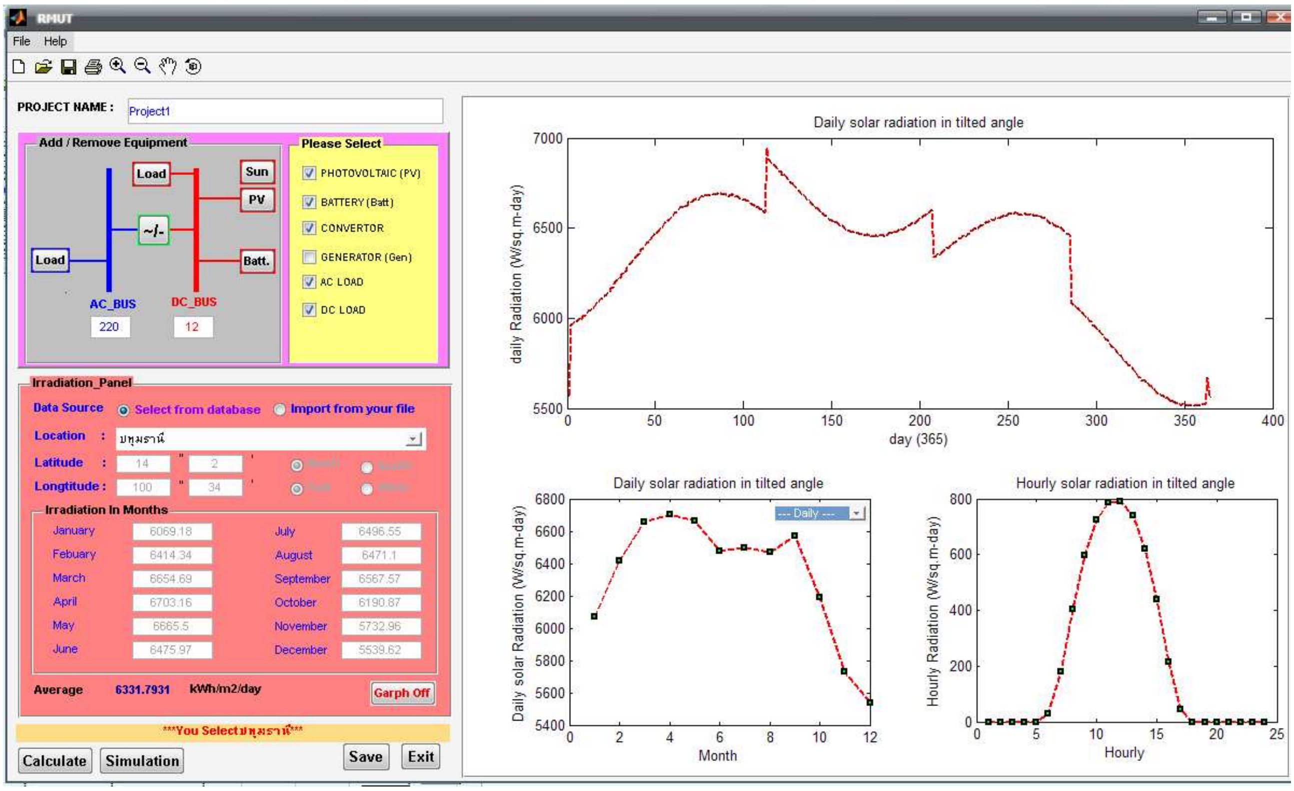

Fig. 3. Experiment for calculation of solar radiation of Phathumthani location.

Table 1. Comparison of the solar radiation

Month	Global Solar Radiation Pratumtani (14' 2,100' 34) (w/m2/day)		error (%)	Global Solar Radiation Chaingmai (18' 47,98' 59) (w/m2/day)		error (%)	Global Solar Radiation Ubonrachtani(15' 15,104' 52) (w/m2/day)		error (%)	Global Solar Radiation Pattani(6' 47,101, 9) (w/m2/day)		error (%)
	Satalite	Simulation		Satalite	Simulation		Satalite	Simulation		Satalite	Simulation	
January	4,822	4,980	-3.27	4,536	4,647	-2.44	5,056	4,676	7.51	5,278	5,315	-0.71
February	5,308	5,317	-0.16	4,969	5,143	-3.49	5,014	5,259	-4.89	5,617	5,570	0.83
March	5,781	5,587	3.35	5,228	5,464	-4.52	5,364	5,578	-3.99	5,936	5,733	3.42
April	6,031	5,887	2.38	5,711	5,797	-1.50	5,922	6,018	-1.62	5,928	5,860	1.14
May	5,836	5,662	2.98	5,906	5,629	4.68	5,886	5,615	4.61	5,708	5,558	2.63
June	5,417	5,524	-1.98	5,406	5,675	-4.98	5,711	5,477	4.10	5,628	5,308	5.68
July	5,050	5,210	-3.17	5,242	5,392	-2.87	5,167	5,196	-0.57	5,028	5,004	0.47
August	5,417	5,520	-1.91	5,106	5,474	-7.22	5,811	5,680	2.26	5,628	5,514	2.02
September	4,789	4,857	-1.42	4,589	4,760	-3.73	5,081	4,907	3.42	5,000	4,956	0.88
October	4,767	4,993	-4.75	4,681	4,772	-1.95	5,106	5,293	-3.67	4,606	4,839	-5.07
November	4,719	4,774	-1.16	4,383	4,567	-4.19	4,625	4,803	-3.85	4,714	4,978	-5.60
December	4,697	4,587	2.35	4,225	4,344	-2.82	4,714	4,548	3.52	4,706	4,845	-2.96
Year	5,219	5,242	-0.42	4,998	5,139	-2.81	5,288	5,254	0.64	5,315	5,290	0.46

After calculation, table 3 is the results of the design. The calculation of the new software carries out the sizing results as shown in table 2 by 2 methods: the proposed software method and the Thumb rule method [6]. Table 3 shows the PV size of 7200 W and the battery 1728 Ah. Comparison with Thumb rule in the first column in table 3, we can see that the software has smaller size than the thumb rule. We can investigate an analysis afterward such as checking the reliability, Loss of Load Possibility (LOLP). Table 4 shows important data such as Unmet load which is zero in this design. The analysis shows also the power generated from PV for every month. We found that there is excess energy to system because the solar energy is produced but no demand. We also can adjust some feature of LOLP to see the trend of energy production in order to make a flexible decision as in table 5. From table 5, we allow 10% of LOLP which means that the system can have a possibility to cut load for 10%. The results of PV size and battery is therefore reduced, PV 3606 Wp, Battery 826Ah, however the energy excess will increase for this analysis. As this feature of the program, we can also investigate other reasons back and forth for the decision such as increase/decrease the LOLP, Battery, or PV size. This is very flexible for system design.

Table 2. Sizing result and specification of equipment

PV sizing	7200 Wp	Batt sizing	41472 Wp
Brand	Shell	Brand	MK
Model	SM50-H	Model	8GUI
Maximum Power	50 Wp	Capacity	36 Ah
Maximum Volt	15.9 V	End of Volt	1.7 V/cell
Maximum Current	3.15 A	Over of Volt	2.3 V/cell
Open circuit volt	19.8 V	Efficiency	95 %
Short circuit Current	3.4 A	Deep Of Discharge	30 %
No_module	144 Set	No_batt	48 Set
PVmodule_serie	2 Set	Battmodule_serie	2 Set
PVmodule_parallel	72 Set	Battmodule_parallel	24 Set

Table 3. The results comparison between the proposed program and hand calculation (thumb rule)

Item	Calculate Method	Tilt Angle	Peak Son	Load AC	Load DC	Nominal Voltage	Battery Capacity	PV Capacity
			(Hr/day)	(W)	(W)	(V)	(Ah)	(W)
1	$\frac{E_{el} \cdot I_{STC}}{E_{glob} \cdot Q}$	14'	4.587	17410	-	24	3449.167	8278
2	This Program	14'	hourly	load profile	-	24	1728	7200

Table 4. PV size is 7,200Wp and battery size is 1,728Ah at LOLP=0%

Month	Energy PV (W)	Energy Demand (W)	Energy Storage (W)	Energy Unmet (W)	Energy Excess (W)	LOLP (%)
Jan	1020011.45	568115.79	394525.77	0	486847.71	0
Feb	988882.62	513136.84	374510.58	0	483934.28	0
Mar	1154820.5	568115.79	415249.55	0	590721.45	0
Apr	1188844.1	549789.47	393694.15	0	648868.76	0
May	1179496.41	568115.79	377013.18	0	652444.53	0
Jun	1110470.85	549789.47	359738.65	0	602837.6	0
Jul	1073300.92	568115.79	371475.34	0	549436.64	0
Aug	1142248.46	568115.79	406281.9	0	586965.97	0
Sep	956262.3	549789.47	379440.29	0	441376.47	0
Oct	1066310.77	568115.79	395259.71	0	535541.52	0
Nov	939319.94	549789.47	375574.66	0	441701.14	0
Dec	931165.99	568115.79	391104.46	0	410702.77	0

PV = 7200Wp Battery = 1728Ah LOLP = 0%

Table 5. The energy for the system is PV size is 3,606Wp and battery size is 828Ah at LOLP=10%

Month	Energy PV (W)	Energy Demand (W)	Energy Storage (W)	Energy Unmet (W)	Energy Excess (W)	LOLP (%)
Jan	510005.73	568115.79	294664.62	133552.67	84151.84	0.24
Feb	494441.31	513136.84	287916.89	100552.67	91209.18	0.2
Mar	577410.25	568115.79	334689.28	89846.8	113355.21	0.16
Apr	594422.05	549789.47	335938.49	66750.65	125543.98	0.12
May	589748.21	568115.79	337074.07	76878.91	111469.69	0.14
Jun	555235.42	549789.47	323494.82	74520.1	95343.11	0.14
Jul	536650.46	568115.79	323929.65	97921.67	72190.5	0.17
Aug	571124.23	568115.79	338272.64	80202.49	91775.85	0.14
Sep	478131.15	549789.47	297219.51	113105.98	54038.02	0.21
Oct	533155.39	568115.79	316761.1	111823.19	87757.51	0.2
Nov	469659.97	549789.47	286242.2	148675.69	63657.41	0.27
Dec	465583	568115.79	283597.57	151977.18	55664.48	0.27

PV = 3606Wp Battery = 828Ah LOLP = 10%

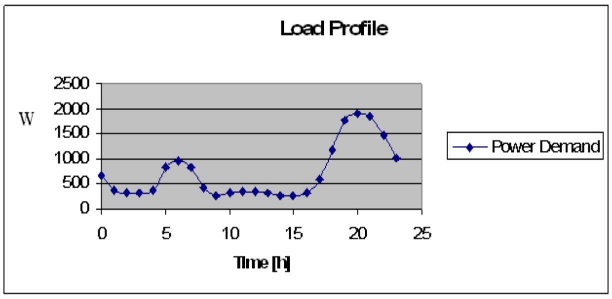

Fig. 4. Example load profile for design and analysis.

Then to prove more reliability of the program, we made a comparison of this program with the well known HOMER program for analysis. We use the same PV-Battery size to simulate, the results show as in table 6, 7. From table 6, the result is the comparison of solar radiation in the location, we can see that the result has average error percentage is only 0.54%. Table 7 shows the energy production at the same PV and battery size, the result has average error percentage of 0.60%.

5. CONCLUSIONS

The paper presents the development of a new software program for designing the PV hybrid system by using MATLAB environment. To design and analysis the PV system, it is necessarily to use the data of global radiation on horizontal surface, therefore this paper also uses the global radiation by having the long term duration of sunshine data record for five years. The data are used for calculation the daily mean maximum duration sunshine in a year, after that, linear relation in Angstrom equation are calculated the global radiation on horizontal surface, next, determining of hourly solar energy on tilt surface, hourly batter capacity, finally program will compare last hourly data with hourly load. The program provides graphic interface for user. The user can input load profile and select the system type via graphic tool box. The program also provides information of system components from industries for system design. The user can select all design components by the provided information. To prove the program design, the selected load profile is input to the program and then simulation with the comparison of Thumb rule. The results show that the program is correctly calculated and had a smaller PV size than the thumb rule method at the LOLP 100%. After program calculation, the new software can also provide analysis tools. User can adjust the LOLP, PV, or Battery size capacity to investigate the PV system. To prove more reliability of new software, the comparison with Homer program is implemented. The results have the error about 0.6%. This can be sure that the proposed software program is able to design and analysis the PV-Hybrid system for target area in Thailand reliably.

Table 6. The energy of solar in tile angle at 14.20°N

Month	A New Active Software (Wh)	Homer (Wh)	Error (%)
January	146,752.675	147,415.000	-0.45
February	148,171.346	149,238.000	-0.71
March	177,413.979	179,192.000	-0.99
April	180,985.340	181,247.000	-0.14
May	181,834.751	178,059.000	2.12
June	165,137.334	163,410.000	1.06
July	161,114.317	156,977.000	2.64
August	174,525.655	168,847.000	3.36
September	137,919.033	142,500.000	-3.21
October	143,937.780	148,983.000	-3.39
November	146,190.549	141,989.000	2.96
December	149,403.586	145,257.000	2.85
Average	159,448.862	158,592.833	0.54

Table 7. The energy of PV in tile angle at 14.20°N

Month	A New Active Software (Wh)	Homer (Wh)	Error (%)
January	819,461.888	812,986.000	0.80
February	784,521.556	784,480.000	0.01
March	903,611.979	895,983.000	0.85
April	838,960.333	864,886.000	-3.00
May	815,660.074	809,360.000	0.78
June	720,705.645	731,685.000	-1.50
July	681,693.642	710,469.000	-4.05
August	788,362.345	786,184.000	0.28
September	683,813.732	698,019.000	-2.04
October	794,779.485	764,492.000	3.96
November	785,139.667	786,410.000	-0.16
December	783,943.005	812,728.000	-3.54
Average	783,387.779	788,140.167	-0.60

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