DESIGN CALCULATION AND ESTIMATING OF PARABOLIC TROUGH SOLAR THERMAL ELECTRIFICATION FOR A MODEL VILLAGE (30 KW)

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Abstract- Solar thermal energy produces immediate environmental benefits. Solar thermal energy can be converted into electrical energy with the help of parabolic trough electrification system. Electricity can be produced directly from thermal energy using solar thermal collectors which can generate heat energy for a working fluid. Myanmar is situated in the Northern hemisphere. Therefore, the solar collectors must be placed south-facing position when the solar radiation is calculated. To generate the required electrical energy of 30 kW, the total area of the installed collectors is about 194 m^2. The concentrator has an aperture of 1.4 m and a length of 1.4 m, while the absorber tube (0.0315 m inner diameter and 0.0325 m outer diameter). The outlet temperature of working fluid (molten salt) was 763.4994°C in April and 752.9932°C in December. As the rated capacity of a model village is greater than 500 W, the selected nominal system voltage must be DC 120 V. In this paper, design calculation of solar thermal electrification consists of calculation of series and parallel collectors, daily load consumption and distribution system for desired loads for day and night, and estimated cost of electrical components for 400 V distribution system.

Keywords- Parabolic Trough Collectors, Daily Load Consumption, Distribution System, Solar Intensity

I. INTRODUCTION

Type of renewable energy sources are hydro, wind, geo thermal, nuclear, and solar energy. Presently, only hydro and wind power plant at good sites can generate electricity in an acceptable cost range, but which are limited sources. However, solar electricity generations are nearly unlimited sources. In general, there are three well known applications of solar energy use: direct use (lighting and drying), direct conversion into electricity (photovoltaic), and direct conversion into heat (hot water production). Many people associate solar energy directly with photovoltaic and not with solar thermal power generation. Although prices for solar thermal generation are slightly more than those of hydro or wind power, it is amongst the most effective renewable electricity technology and its supply is not restricted if transported from the world's solar belt to the population centre.

There are three types of solar thermal generation in general. They are parabolic dish, parabolic trough, and central receiver or power tower system. There has been a long history of linear solar thermal power systems. The first parabolic trough collector was demonstrated in the late 1860's in France, however, it was not until 1913 that useful mechanical power was produced from solar energy in a 41 kW pumping system installed in Egypt by Shuman.

Then a large solar thermal system installed at the Phoenix Federal Correctional Institution (FCI) in 1998 for the prison and costs less than buying electricity to produce 3.4 million Btu/hr (1000 kW) of heat at 60 percent peak system efficiency. Figure.1 shows schematic diagram of parabolic trough solar thermal electrification. All the components of figure show in design calculation.

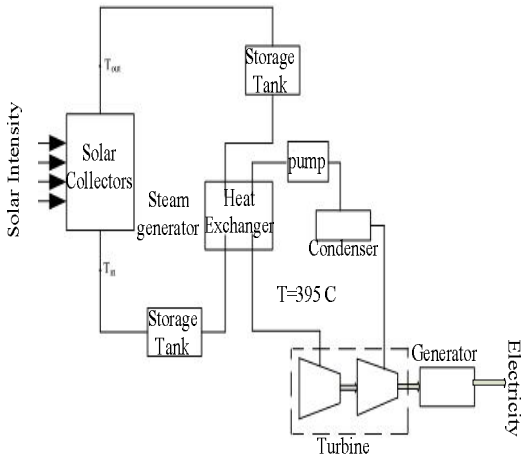


Figure. 1. Schematic diagram of parabolic trough solar thermal electrification

II. DESIGN CALCULATION

A. Geometry of Wyagyi Village

Wyagyi village is situated between North Latitude 20˚ 25´ and East Longitude 96˚ 09´. The elevation above sea level is 74.676×10^{-3} km and situated Mandalay Region within tropical zone.

The local standard time of meridian is 97˚ 30´ E. The temperatures, sunshine hour and total solar radiation of Wyagyi village for the year 2014 are maintained in Table 1 and Table 2. The data are obtained from Department of Meterology and Hydrology (Myanmar – Wyagyi village).

Table. 1 Temperatures (˚C) and Sunshine Hour of Wyagyi Village

Month	Temperature˚ C	Sunshine hour
January	31.7	7.8
February	36.3	9.5
March	38.5	9.2
April	40.1	10.8
May	35.6	11.2
June	34.0	9.3
July	33.0	9.0
August	31.4	9.2
September	32.2	9.0
October	31.4	8.5
November	31.3	7.4
December	27.8	6.8

Table. 2 Total Solar Radiation for Horizontal Surface(MJ/m^2)

Time (hr)	April	December
6-7 am	0.29707	1.11567 x 10^{-5}
7-8 am	0.92317	0.41511
8-9 am	1.49227	0.995211
9-10 am	1.5875	1.53001
10-11 am	1.99767	1.9236
11-12 am	2.21167	2.1305
12-1 pm	2.21167	2.1305
1-2 pm	1.99767	1.9236
2-3 pm	1.5875	1.53001
3-4 pm	1.49227	0.995211
4-5 pm	0.92317	0.41511
5-6 pm	0.29707	1.11567 x 10^{-5}
Total(MJ/m²)	17.0187	13.9888
(W/m²)	4727.4166	3885.8011

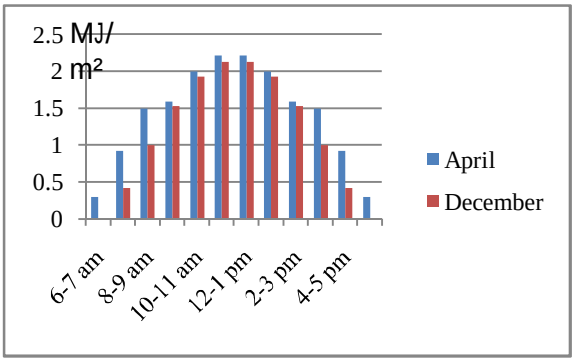


Figure. 2. Variation of Solar Intensity and Time

Figure 2 shows variation of solar intensity and time in April and December.

B. Design Calculation Data of Parabolic Trough Date April 15 =40.1˚ C and December 15= 27.8˚ C

Specular reflectivity of the concentrator surface, ρ	0.94
Glass cover transmittivity for solar radiation, τ	0.88
Absorber tube emissivity /absorptivity, α	0.96
Intercept factor, ?	0.95
Mass flow rate, m	0.09 kg/s
Inlet temperature, T_{fi}	60˚ C

(i)The equations of absorbed flux, useful heat gain and exit temperature Absorbed flux,

$$S = I_b r_b \rho\gamma (\tau\alpha)_b + I_b r_b (\tau\alpha)_b \left(\frac{D_o}{W - D_o} \right) \quad (1)$$

Useful heat gain,

$$q_u = F_R (W - d_{co}) L \left[S - \frac{U_L}{c} (T_{fi} - T_a) \right] \quad (2)$$

Exit temperature,

$$mc_p \Delta T = q \quad (3)$$

The table 3 shows results of absorbed flux, S. Table 4 and 5 show results of useful heat gain and exit temperature in April and December.

Table. 3 Results of absorbed flux, S in April and December

Time (hr)	S (April) W/m²	S(December) W/m²
6-7 am	63.9096	2.400x10^{-3}
7-8 am	198.6056	89.3042
8-9am	321.0383	214.1041
9-10 am	341.5257	329.1578
10-11 am	429.7673	413.8323
11-12 am	475.8065	458.344
12-1 am	475.8065	458.3442
1-2 am	429.7673	413.8323
2-3 am	341.5257	329.1579
3-4 am	321.0383	214.1045
4-5 am	198.6056	89.3042
5-6 am	63.9096	2.400x10^{-3}
Total	3661.306	3009.4903

Table. 4 Results of the useful heat gain

Time (hr)	April (Q) kW	December (Q) kW
6-7 am	76.4278	-67.3607
7-8 am	325.2518	97.6066
8-9 am	551.4219	328.1496
9-10 am	589.2683	540.6884
10-11 am	752.2770	697.1077
11-12 am	837.3254	779.3346
12-1 pm	837.3254	779.3346
1-2 pm	752.2771	697.1077

2-3 pm	589.2683	540.6886
3-4 pm	551.4219	328.1503
4-5 pm	325.2518	97.6066
5-6 pm	76.4278	-67.3607
Total	5970.6927	3971.7187

Table. 5 Results of exit temperature in April and December

Time (hr)	April (T_{fo})	December (T_{fo})
6-7 am	60.5307	59.5322
7-8 am	62.2587	60.6778
8-9 am	63.8293	62.2788
9-10 am	64.0921	63.7548
10-11 am	65.2241	64.8410
11-12 am	65.8148	65.4120
12-1 pm	65.8148	65.4120
1-2 pm	65.2241	64.8410
2-3 pm	64.0921	63.7548
3-4 pm	63.8293	62.2788
4-5 pm	62.2587	60.6778
5-6 pm	60.5307	59.5322
Total	763.4994	752.9932

C. Calculation of series and parallel collectors for 30 kW

The second law of thermodynamics addresses the inherent of irreversibility of processes and leads to the ultimate limiting conversion efficiency of a heat between isothermal reservoirs. Mass flow rate by collector and the total mass flow rate depend on the connection-type between solar collectors. The parallel arrangements between collectors increase the total flow rate entering the storage tank that destroys the statification and in this case series-parallel combinations are preferred. The solar collectors were installed 9 collectors in series and 11 collectors in parallel.

$$\eta = \frac{P_{turbine}}{P_{working}} \tag{4}$$

$$\eta = 1 - \frac{T_t}{T_w} \tag{5}$$

Parallel collectors: $Nc = \frac{T_t}{T_s}$ (6)

where, T_t = total temperature ,

T_s = simple temperature

Turbine power,

$$Q = m_t c_p \Delta T \, , m_t = \frac{Q}{c_p \Delta T} \tag{7}$$

Series collectors:

$$Nr = \frac{m_t}{m_s} \tag{8}$$

where, m_t =total mass flow rate,

m_s =simple mass flow rate

III. DESIGN CALCULATION OF LOAD SIDE

There are 54 numbers of water pumping motors and each motor consumes 273.24 W. Its maximum working hour is only one. Its power factor is 0.92, working current is 1.35 A and working voltage is 220 V respectively. Daily load duty cycle with working hours is shown in Table 6.

Table. 6 daily load duty cycle of Wyagyi village

Load Description	Power Consumption W	Qty	Working hours	Daily Load Consumption $Whday^{-1}$
Water pumping Motors	273.24 (single phase)	54	1	14755
		Total	At day	14755
Street lamps	15	30	12	5400
LED bulbs	15	108	4	6480
4 ft fluorescent Lamps	50	54	3	8100
televisions	55	52	3	8580
		Total	At night	28560

Although the load profile is 30 kW, the daily load consumption is not more than 28 kW. It is because of separate supply with two periods, day and night. The maximum power load consumption at night is 28560 Wh and 14755 Wh at day.

In this paper, daily load consumption (Ah/day)at day is 144.66 Ah/day and at night is 280 Ah/day in where power conversion efficiency is 0.85 and nominal system voltage is 120 V (P_{gen}>5000W). And then corrected Ah load consumption is 164.01 Ah/day at day and 317.46 Ah/day in where wire efficiency factor is 0.98 and battery efficiency factor is 0.9.

There are 15 numbers of street lamps, 15 numbers of LED lamps, 50 numbers of fluorescent lamps and 55 numbers of televisions per phase and they are supplied symmetrically at night.

At the day time, the 18 numbers of AC motors per phase are also supplied symmetrically. System design currents based on solar energy data are 124.36 A in April and 151.292 A in December. Load sharing to village is as shown in Figure.

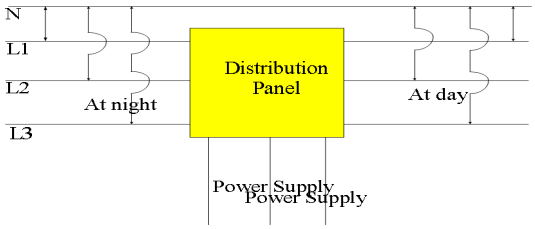


Figure. 3. Load sharing from the distribution panel with two Periods

IV. DISTRIBUTION DESIGN

The Distribution system is based on the Myanmar standard voltage which is 400 V for the three phase and 230 V for the single phase distribution system. Power frequency is 50 Hz. Recommendations towards specific design criteria, material and equipment consider the envisaged construction methodology and operation approach (both are community based) and the remoteness and accessibility of construction sites. The distribution line of Wyagyi village is 1615 feet long added to 10 percent of total length. The calculation of line length is 1776 feet. Therefore, the total number of 20 poles will be constructed. Not only the arm number 1 to 8 with 400 V double arms but the arm number 9 to 20 with 400 V single arms will be distributed electricity.

The arm number 1 is exist starting pole, the arm number 5 and 8 are the ending poles and the arm number 4, 2 and 6 are suspension poles of 400 V double arm distribution line. Moreover, the arm number 5, 3, 1 and 7 are the starting poles, that of 11, 14, 17 and 20 are the ending poles and that of 9, 10, 12, 13, 15, 16, 18 and 19 are the suspension poles of 400 V single arm distribution line. The distance between pole 1 and 2 is 75 feet and pole 2 and 3, pole 3 and 4 and pole 4 and 5, pole 1 and 6 and pole 6 and 7 have similar values. Additionally, pole 5 to 9 to 10, pole 3 to 12 to 13, pole 1 to 15 to 16 and pole 7 to 18 to 19 are 90 feet respectively. Between pole 10 and 11, 13 and 14, 16 and 17 and 19 and 20 are 85 feet distance. The distribution line design is shown in Figure 4.

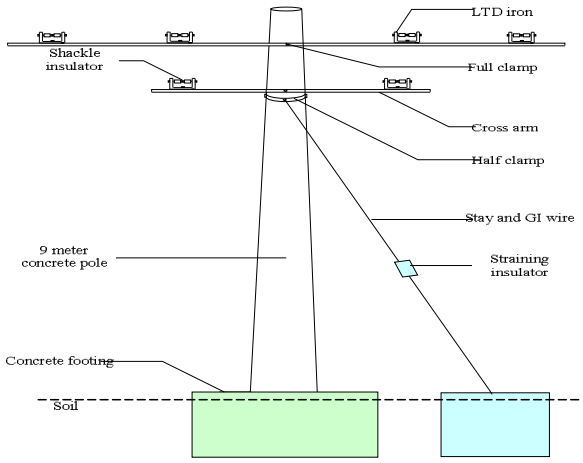


Figure. 4 400 V Single and Double Cross Arm with 9 meter

Concrete Pole Structure

For pole 1 (starting arm),
arm = 3 nos.
sp iron = 8+2 = 10 pairs (nut = 20)
SI = 10 nos.
FC = 1 (nut =2 nos.)
HC = 2 pairs (nut=4 nos.)
stay = 1 set
St insulator = 1 no.
fuse side = 3+3+1 = 7 nos.
nut = 20+2+4 = 26 nos.

For pole 8 (ending arm),
arm = 1 no.
sp iron = 4 pairs (nut = 8 nos.)
SI = 4 nos.
FC = 1 (nut =2 nos.)
HC = 1 pair (nut=2 nos.)
stay = 1 set
St insulator = 1 no.
nut = 8+2+2 = 12 nos.

For pole 5,
arm = 2 nos.
sp iron = 4+2 = 6 pairs (nut = 12 nos.)
SI = 4+2 = 6 nos.
FC = 1+1 = 2 nos. (nut =4 nos.)
HC = 1+1 = 2 pairs (nut=4 nos.)
stay = 2 sets
St insulator = 2 nos.
fuse side = 1 = 1 no.
nut = 12+4+4 = 20 nos.

Foe pole 7, 3 (calculate for one pole only),
arm = 2 nos.
LT D iron = 4 nos. (nut= 8 nos.)
sp iron = 2 pairs (nut= 4 nos.)
SI = 4+2 = 6 nos.
FC = 1+1 = 2 nos. (nut =4 nos.)
HC = 1 pair (nut=2 nos.)
stay = 1 sets
St insulator = 1 nos.
fuse side = 1 no.
nut = 8+4+4+2 = 18 nos.

For pole 11, 14, 17, 20 (calculate for one pole only),
arm = 1 no.
sp iron = 2 pairs (nut = 4 nos.)
SI = 2 nos.
FC = 1 nos. (nut =2 nos.)
HC = 1 pair (nut=2 nos.)
stay = 1 set
St insulator = 1 no.
nut = 2+4+2 = 8 nos.

For pole 4, 2, 6 (calculate for one pole only),
arm = 1 no.
LTD iron = 4 nos. (nut= 8 nos.)
SI = 4 nos.

FC = 1 no. (nut =2 nos.)
nut = 8+2 = 10 nos.

For pole 9, 10, 12, 13, 15, 16, 18, 19 (calculate for one pole only) ,
arm = 1 no.
LTD iron = 2 nos. (nut = 4 nos.)
SI = 2 nos.
FC = 1 no. (nut =2 nos.)
nut = 4+2 = 6 nos

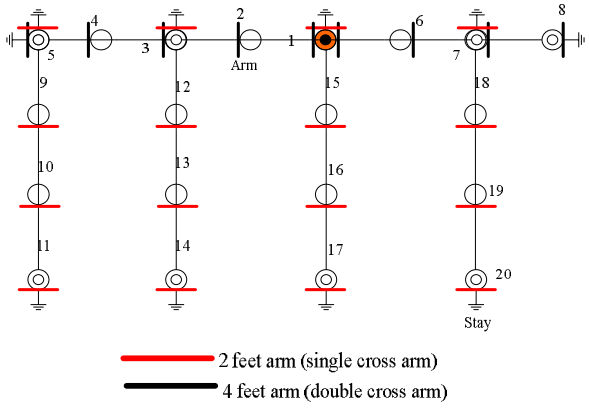


Figure. 5 Distribution line design of Wyagyi village

The figure 5 shows the distribution line design of Wyagyi village. Figure 6 shows the distribution among poles of distribution system.

the distance between pole 1 and pole 5 = (75 × 4) = 300 ft

the distance between pole 1 and pole 8 = (75 × 2) + 105 = 255 ft

the length of four wires between pole 5 and pole 8= (300 + 255) ×4 =2220 ft

the distance between pole 5 and pole 11 = 90 + 90 + 85 = 265 ft

the distance of four parallel distribution line= 265× 4 = 1060 ft

the length of two wires for four parallel line= 1060× 2 = 2120 ft the total length of wires= 2220 + 2120 =4340 ft

the total length of wires for distribution system = 4340 + 10 % of total length= 4340 + 434= 4774 ft

The length of 17 ft wire is 1 kg weight. Therefore,

the total weight of wire = $\frac{4774}{17} \times 1$ = 280 kg

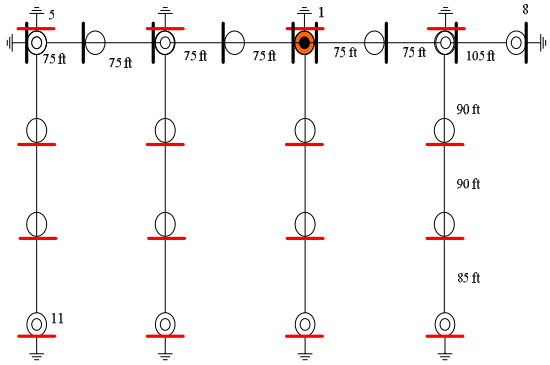


Figure. 6 The Distance among Poles of Distribution System

V. ESTIMATED COST OF ELECTRICAL COMPONENTS FOR 400 V DISTRIBUTION SYSTEM OF A MODEL VILLAGE

Table. 7 Estimated cost of electrical components for 400 V distribution system of Wyagyi village

No	Description	Unity	Qty	Rate	
	Material charges				
1	9m concrete pole(existing) Cement for concrete footing Sand for concrete footing Gravel for concrete footing Fitting structure charges for stay	Nos. Bag Cu.ft Cu.ft Nos.	20 37 266 531 10	- 5000 100 300 1500	- 185000 26600 159300 15000
2	Angle iron (2.5 x2.5x4.5)/cross arm	Nos.	9	8000	72000
3	Angle iron (2.5 x2.5x2.5)/cross arm	Nos.	16	4500	72000
4	Full clamp for cross arm	Nos.	23	1500	34500
5	Half clamp for stay	pair	11	2000	22000
6	GI wire for stay	kg	22	2500	55000
7	Shackle insulator	Nos.	68	400	27200
8	Straining insulator	Nos.	10	900	9000
9	Stay rod complete set	pair	10	8000	80000
10	Flat iron for strap	pair	32	1000	32000
11	Insulator loop strain (400 V fuse side)	Nos.	10	900	9000
12	Copper binding wire	kg	5	12500	62500
13	HDBC No.6 for 3 phase 4 wires	kg	280	12000	3360000

14	3 phase 200 A MCCB	Nos.	1	210000	210000
15	XLPE cable (50 mm²)	m	20	12100	242000
16	Insulation tape	Nos.	10	300	3000
17	PVC pipe	Nos.	1	12500	12500
18	PVC elbow	Nos.	4	1500	6000
19	LTD iron	Nos.	36	750	27000
20	400 V outdoor panal with bus bar	Nos.	1	330000	330000
21	Bolt and nuts with washer	Nos.	230	200	46000
22	digging for pole digging for stay	Nos. Nos.	20 10	2000 1500	40000 15000
23	Service charges Survey and setting charges	ft	1780	30	53400
24	Fitting charges (arm, insulator, LTD iron)	Nos.	25	2000	50000
25	transportation charges for materials installation and other charges	- -	- -	- -	50000 149000
	Grand total cost				5,455,000

VI. DISCUSSION AND CONCLUSION

Technical evaluation of a Solar Parabolic Trough System was performed in Wyagyi village, Thazi Township in Mandalay Division. To generate the required electrical power energy of 30 kW, the total area of the installed collectors is about 194 m^2, 9 collectors in series and 11 collectors in parallel. The desired temperature can be increased by using the larger absorber area. Although it has some disadvantages, all of the above involved materials that are far cheaper than photovoltaic. In this paper, detail design calculations of heat gain, load distribution system for day and night, and distribution system by time zones are presented and calculated. From the temperature data of year 2014, the maximum temperature is occurred at April and the minimum temperature is occurred at December. The heat gain from collector to receiver, working fluid heat energy and the storage system are also concerned with temperature variation. The solar thermal system can reduce carbon emission and cost of transmission losses. At present, there is still no practical experience in the operation of this power plant technology in Myanmar. This paper has been carried out on the development of solar thermal electrification system for a model village.

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