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Urban Metro Elevated Station to Generate Solar Power

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Abstract: This paper is focused to understand the practicality and projected analysis to utilize urban metro elevated stations as solar electricity power generation by utilizing the roof area in m^2 for solar panel installation to generate electricity based on renewable and sustainable energy. Mass Rapid Transit Klang Valley Line 1 of Kuala Lumpur, Malaysia has been selected for this research study. Ultimately this will help to mitigate environmental issues and helps to contribute current electricity demand load challenges faced by energy service providers. Solar power works at maximum output with favorable parameters and Kuala Lumpur has an annual average of solar irradiance of 4.9 kWh/m^2/day, ambient temperature 25.53°C, wind speed 2.24 m/s and air mass (A.M) 1.5. In addition, urban metro elevated stations roof area for stations can be utilized by installing solar panels which indirectly able to bring revenue collection to stakeholders. Some of the key challenges in this research are selection of the best solar panels, inverters and medium voltage stations including the return on investment (ROI).

Keywords: Optimal Solar panels, inverters, medium voltage station, O&M, total initial cost, ROI

1. Introduction

Electricity energy demand increase year to year in Malaysia due to massive development, the power load demand projected by TNB estimated 24,598 MW by year 2030 and to cater required more power plants (Energy Planning Challenges from TNB perspective, 2014). The dependency on fossil fuel for electricity generation emits to huge green gas house gases (GHG) (Syed Shah Alam, Nor Aisah Omar, Mhd. Suhaimi Bin Ahmad, H. R. Siddiquei and Sallehuddin Mohd Nor,2013). United Nation (UN) has developed 17 Sustainable Development Goals (SDGs) in 2015 to mitigate many global issues and to transform our world. Our research study is aligned to one of the SDGs, which is "climate change". On the other hand, in Malaysia we have Sustainable Energy Development Authority (SEDA) and Ministry of Energy, Green Technology and Water (KeTTHA) which is looking into possibilities of electricity generation by renewable resources to cater future load demand by mitigate non-renewal electricity generation plants which projected to be constructed by service providers and urged construction industries to build by prioritized Green Building Index (GBI) to mitigate load demands (SEDA, 2009). The feed-in tariff incentives offered by SEDA and KeTTHA for solar system installer in generally three times higher rate compared to TNB charges for per Kilowatt hour (kWh) and the contract valid for 21 years (SEDA, 2015).

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Attractive incentives and recognition are given for GBI rated buildings as encouragement from the government on the implementation of GBI (GBI, 2011, Siti Zubaidah Hashim, Intan Bayani Zakaria, Nadira Ahzahar, Mohd Fadzil Yasin and Abdul Hakim Aziz, 2016). The Mass Rapid Transit (MRT) elevated stations has been constructed in an urban city in Klang Valley, Malaysia with huge and big area in m2 of structured steel roof truss as shelter for stations which can be utilized by installing solar panels (AECOM, 2012). Singapore Mass Rapid Transit (SMRT) has been implemented solar powered energy for depot (SMRT, 2016).

Solar photovoltaic monocrystalline and polycrystalline market demand is growing rapidly with annual growth of 35-40% with efficiency close to theoretical predicted maximum values (Razykov, Ferekides, Morel, Stefanakos, Ullal, and Upadhyaya, 2011). Solar PV power plant is getting popular in Malaysia since 2011 with the encouragement from the government and there are numbers of feasibility studies pertaining to solar system on going while year to year the research and solar power plant increasing uptrends (Pauzi Kassim, Karam Al-Obaidi, Arkan Munaaim and Abd Mokhti Salleh, 2011).

1.1 Structure

Key elements for this research to structure the strategies and sequences to navigate the research in the correct direction to meet the desired objectives are shown in fig. 1. The key elements and sequences for this research are as followings,

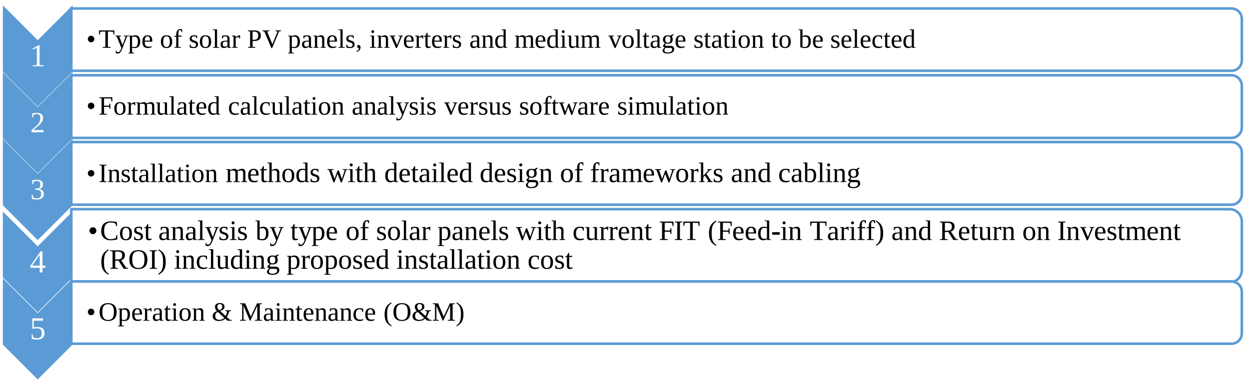

Fig. 1 – Research Structure

1.2 Schematic Diagram Connection

The installation of solar panels and inverters by using mounting systems which specially made for solar systems (Inox-Mare Solar, 2011) and shown in fig. 2. Arrangement of panels by using string known as series connection and array known as parallel connection to an inverter by limitation of inverter.

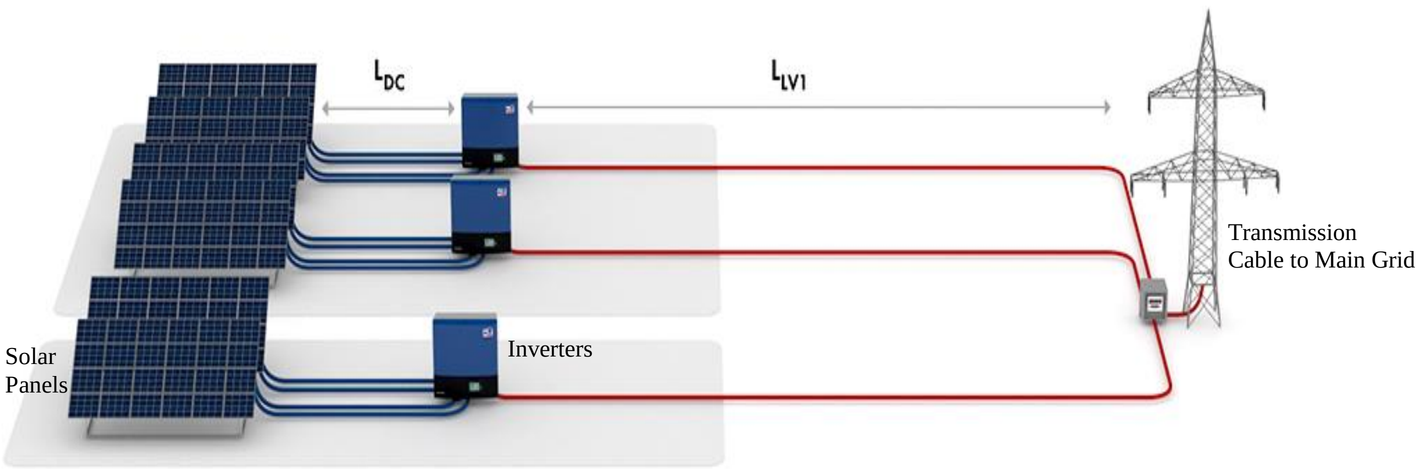

Fig. 2 – Schematic Diagram

1.3 Solar Panel Cross Section Perspective and Tilt Angles

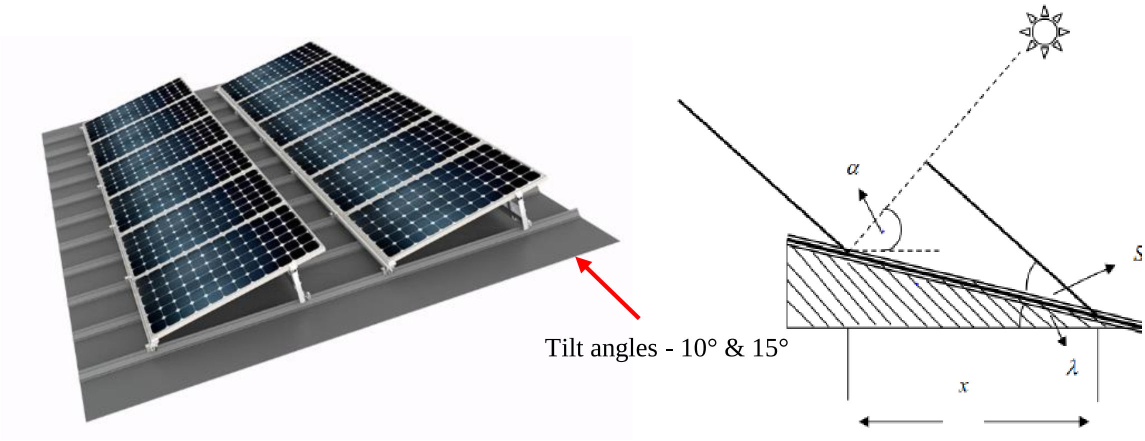

Fig. 3 – (a) Cross Section; (b) Tilt Angles

Figure 3 shows the specific tilt that produces a maximum output in the efficiency of the PV system. In principle, a tilt of 10 -15° would be the ideal one to maximize the power generation. Thus, in our simulation we have used 15° which will be shown in our result.

2. Material Selection

2.1 The Solar Panel Selection

Solar panel selection is depending on the properties of mechanical and electrical parameters followed by its price per panel and the warranty period. Inevitably photovoltaic device and solar irradiance control Pmax (watts peak) = Vmp (maximum power voltage) x Imp (maximum current voltage) of solar panel (Solmetric, 2011).

Total of 4 types of solar panel were selected for this research Jinko JKM320PP-72 305-320W, Sova Solar SS320P-72 (03/2016), SPR-E20-327-COM (08/2016) and SPR-E20-435-COM (03/2016). Solar panel key parameters capacity (watts peak) by panels, module efficiency %, panel dimension m^2, price, warranty and power guarantee degradation by solar panel makers (Jinko Solar, 2015, Sova Solar, 2016, Sun Power, 2016). All the specifications are shown in table 1.

Table 1 - Solar Panel Comparison by Makers

Solar Panel Comparison	Jinko JKM320PP-72 305-320 Watt	Sova Solar SS320P-72 (03/2016)	SPR-E20-327-COM (08/2016)	SPR-E20-435-COM (03/2016)
Pmax (Wp)	320	320	327	435
Vmp (V)	37.4	36.56	54.7	72.9
Imp (A)	8.56	8.76	5.98	5.97
Voc (V)	46.4	45.01	64.9	85.6
Isc (A)	9.05	9.11	6.46	6.43
Module Efficiency %	16.49%	16.67%	20.30%	20.30%
Dimension (mm)	1956 x 992 x 40	1955 x 982 x 42	1559 x 1046 x 46	2073 x 1072 x 46
Panel Dimension m2	1.94	1.92	1.63	2.23
Weight Kg (Ibs)	26.5 (58.4)	22.1(48.7)	18.6 (41)	25.4 (56)
Price (RM)	1012.00	700.00	1711.00	2381.00
PV Type	Poly	Poly	Mono	Mono
Warranty (Yrs)	25	25	25	25

2.2 The Inverter DC to AC Selection

Inverters are crucial equipment to convert DC power source receive from solar panels to AC power source by rated capacity. There are many types of inverter manufacturers with comparable price and rated capacity. To narrow down the selection of inverters, the most important aspects is total warranty period can be guaranteed by inverter makers.

From the findings (shown in table 2), identified SMA Solar Technologies headquarters in Germany guaranteed inverters with total of 20 years with extended warranty package and comprehensive maintenance coverage compared to other makers mostly up to 15 years maximum without comprehensive maintenance [Sun Power, 2016]. Thus, inverter SMA model Sunny Tripower 15000TL (SMA 15 kW) and Sunny STP-60-10 (SMA 60 kW) were selected for this research (Sunny SMA, 2016).

Table 2 – Inverter DC to AC by Rated Power

SMA Inverter Comparison	**SMA - Sunny Tripower 15000TL**	**SMA - Sunny STP - 60 -10**
Input DC		
Max DC	15330W	61240W
Max Input Voltage	1000 V	1000 V
MPP Voltage Range	240 V - 800 V	570 V - 800 V
Min Voltage/Start Voltage	150 V/188 V	565 V / 600V
Max Input Current A & B	30 A /30 A	110 A
Output DC		
Rated power	15000 W	60000 W
Max AC Apparent Power	15000 VA	60000 VA
Max Current/Rated Current	29 A / 21.7 A	87 A
Max Efficiency	98.40%	98.80%
Standard Warranty (Yrs)	5	5
Extended Warranty Max (Yrs)	20	20
Extended Warranty Price (RM)	5,098.67	12,853.65
Inverter Price (RM)	14,921.55	30,024.99

2.3 AC Medium Voltage Station Selection

Medium voltage Station (MVS) are required to combine those DC-AC inverters by receiving AC input kVA prior to connect main grid. From the findings (shown in table 3), to standardize and compatibility of the system, SMA Solar Technologies MVS model MVS-600-STP10 (Rated 600 kVA) and SMA MVS-1200-STP10 (Rated 1200 kVA) were selected in this research [Sunny SMA, 2014, 2016). MVS required units to be finalized once solar panel and inverter has been selected. In general, manufacturers only offer 5 years warranty as a standard product and no extended warranty packages available. On the other hand, the cost will be a premium rate to cover additional 2 years.

Table 3 – AC Medium Voltage Station

SMA Central Inverter	SMA MVS - 600 -STP 10 for 10 Tripower 60 Inverter	SMA MVS - 1200 - STP 10 for 20 Tripower 60 Inverter
Input Rated power	600KVA	1200KVA
Input Nominal Voltage	400 V	400 V
Power Frequency	50 Hz / 60 Hz	50 Hz / 60 Hz
Min Input Current at Nominal Voltage	150 V/188 V	565 V / 600V
Max Input Current A & B	870 A	1740 A
Output Nominal Voltage	20 KV	20 KV
Output Optional Nominal Voltage	10 KV - 34.5 KV	10 KV - 34.5 KV
Max Efficiency	99.30%	99.30%
Standard Warranty (Yrs)	5	5
Inverter Price (RM)	160,499.61	300,024.99

3. Computerized Simulation Versus Formulated Formulas

Numbers of computerized software simulation are available to analyze solar simulation. For this research, Sunny Web Design were selected as benchmark verification for formulated calculation by stations.

Formulated formulas are crucial for this research, equation (1) used to identify total solar panels required in total, equation (2) explained total price for required solar panels related to equation (1), equation (3) explains total kWp able to be generated from solar panels, equation (3.4) derived total required inverters proportioned to equation (3), equation (5) to capture total required medium voltage station based on equation (4), equation (6) and (7) total price for inverters and medium voltage station respectively and equation (8) to identify projected total kWh able to be generated from the proposed solar system. Refer to those equation as shown,

Total Solar Panel (Total SP),

$$= \frac{\text{Total Roof Area (TRA) m}^2 - \text{Maintenance Access (MA) 20\% m}^2}{\text{Panel Size m}^2} \tag{1}$$

$$\text{Total SP Price} = \text{nSolar Panels x Price Per Unit} \tag{2}$$

$$\text{Total Kilowatts peak (Total kWp)} = \text{Vmp x Imp x nSolar Panels} \tag{3}$$

$$\text{Total Inverter (TI),} = \text{Total kWp / Inverter (Inv) DC by Capacity} \tag{4}$$

Total Medium Voltage Station (MVS), n

$$= \frac{\text{(nTI x Inv AC Apparent Power)}}{\text{MVS Input Rated Power}} \tag{5}$$

$$\text{TI Price} = \text{nInv x Price Per Unit} \tag{6}$$

$$\text{Total MVS Price} = \text{nInverters x Price Per Unit} \tag{7}$$

Total Kilowatt Hour (Total kWh),

$$= \text{Total kWp x Solar Irradiance Hours x SP Efficiency \% x Inv Efficiency \% x MVS efficiency \% - VD (<1\%)} \tag{8}$$

3.1 Computerized Simulation Versus Formulated Formulas

Cost analysis formulated as followings, where Total Initial Cost (TIC),

$$Total\ Initial\ Cost, TIC = \sum_{i=1}^{n} Total\ SP + \sum_{i=1}^{n} Inv + \sum_{i=1}^{n} MVS + Warranty\ Purchases + Installation\ cost \quad (9)$$

$$Total\ Revenue, TR = \sum_{i=1}^{n} TkWh/year\ x\ FIT \quad (10)$$

$$Total\ Cost, TC = \sum_{i=1}^{n} O\&M + Loan\ Payment \quad (11)$$

The Return on Investment works as following formulated,

$$ROI = \frac{Total\ Revenue - Total\ Cost}{Total\ Cost}\ x\ 100\% \quad (12)$$

Bank loan calculation as followings, where payment (A), principal (P), Interest rate (r), payments per year (n) and time in years (t)

$$A = P.\ r(1+r)^{n} / (1+r)^{n} - 1 \quad (13)$$

3.2 Operation and Maintenance for Sustainability (O&M)

For better sustainability, O&M is very important for the reliability of solar system to function at optimal level with longer life cycle as designed.

Lacking in O&M procedures will deteriorate performance and efficiency of solar system and manufacturer have rights to reject warranty claims due to improper O&M (Josh Haney and Adam Burstein, 2013). O&M scheduled maintenance mainly on solar panel surface cleaning, connectors checking, MVS, cable megger test if required and others. Total of RM 500,000.00 provisioned for O&M purpose.

4. Results and Discussion

4.1 Total Roof Area in m^2 by Stations

TRA are obtained from each station roof area and 20% are reserved for *MA*. For example, station 1, TRA 8686 m^2 and the permissible solar panel installation is 6949 m^2.

The maximum permissible area is 7381 m^2 and the minimum is 2618 m^2 out of 24 stations. From the result, TRA is 105168 m^2 with μ (mean) of 4382 m^2 and the permissible solar panel installation is 84144 m^2 with μ of 3506 m^2 as shown in fig. 4.

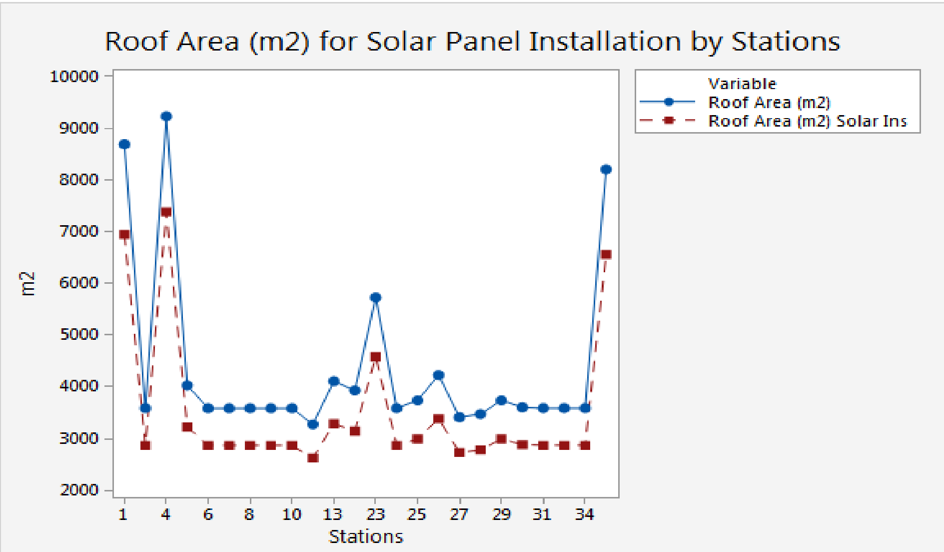

Fig. 4 – Roof Areas by Stations in m^2

4.2 Total Solar Panels Required

Total SP required has been identified based on result 1 by stations versus dimension of solar panel. From the result, the highest panels required is Sun Power 327W with total of 51617 units followed by Jinko 320W is 43369 units, Sova 320W is 43821 units and the lowest by Sun Power 435W is 37899 units as shown in fig. 5. The mechanical factors by dimension played key role in total panels that able to be accommodated in certain area. The smaller the panel dimension, the better numbers can be accommodated.

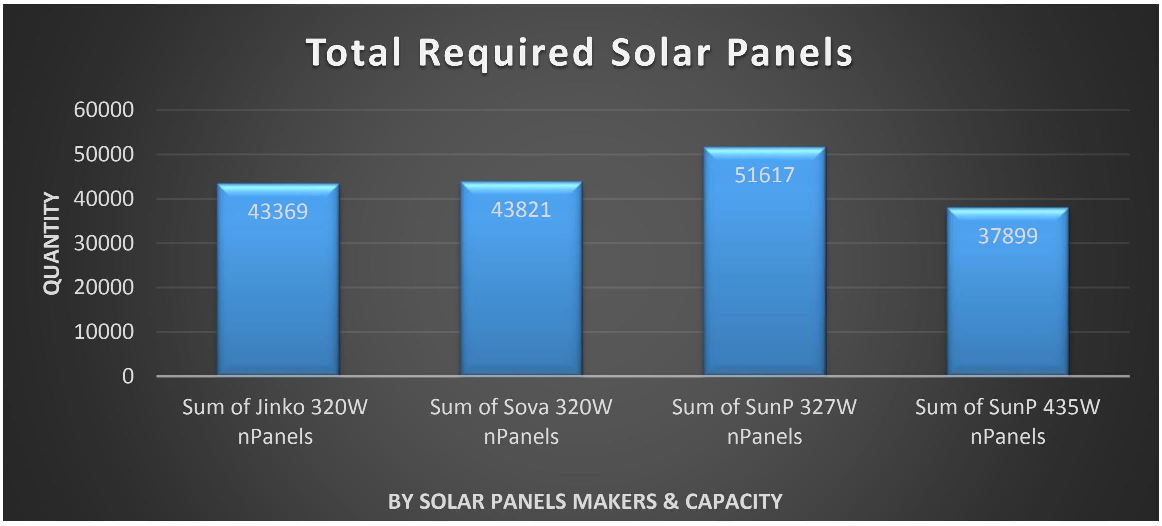

Fig. 5 – Solar Panel Required Quantity

4.3 Total Inverters (TI) Required

TI are based on *Total kWp* to understand how many numbers of inverters are required by capacity or the amount of DC *kWp* able to absorb by the inverters. From the formulated findings, inverters by capacity of SMA 15 kW and SMA 60 kW required 925 and 231 units respectively for Jinko 320W followed by 935 and 234 units respectively for Sova 320W while 1125 and 281 units respectively for Sun Power 327W and 1099 and 275 units respectively for Sun Power 435W. Noticed smaller type of inverters are required more to accommodate larger *Total kWp* based on result 2 while vice versa for higher capacity.

4.4 Initial Cost Comparison by Type of Solar Panels and Inverters

Based on result 2 and 3 findings, the highest total cost for solar panels leads by Sun Power 435W – RM 91.75 million followed by Sun Power 327W – RM 49.29 million, Sova 320W- RM 41.41 million and lowest Jinko 320W – RM 41.20 million.

For inverters, comparison based on SMA 15 kW and SMA 60 kW, the highest total cost leads by SMA 15 kW for Sun Power 327W – RM 14.29 million followed by Sun power 435W – RM 13.96 million, Sova 320W – 11.87 million and Jinko 320W – RM 11.75 million while significant lower total cost for SMA 60 kW compared to SMA 15 kW by highest leads by Sun Power – RM 8.59 million, Sun Power 435W – RM 8.39 million, Sova 320W – RM 7.14 million and Jinko 320W – RM 7.06 million. Inverter are proportional to *Total kWp* of solar panels and to understand how many numbers are required to accommodate in the system for better performance. For larger *Total kWp*, the higher rated inverters are recommended for lower inverter purchasing cost.

4.5 Total kWp & kWh (Solar Irradiance = 1 Hour) by Solar Panels and Inverters

Total kWp are based on solar panels while *Total kWh* are referred after consideration of overall losses during transmission from solar panels to grid line including voltage drops and inverter efficiency. From the projected output, which are based on formulated calculation for 1-hour solar irradiance showed, the best Total kWp produced by Sun Power 327W – 16518 kWp followed by Sun Power – 16486 kWp, Sova 320W – 14023 kWp and lowest by Jinko – 13878 kWp.

For *Total kWh*, the inverter was compared between SMA 15 kW and SMA 60 kW to understand the performance, the output for Sun Power 327W – 15179 and 15241 kWh respectively, for Sun Power 435W – 15150 and 15212 kWh respectively which are comparable performance with Sun Power 327W, for Sova 320W – 13158 and 13211 kWh and Jinko 320W – 13089 and 13142 respectively. From the projected output result, the most optimal and maximum kWp by Solar Panel Sun Power 327W due to mechanical dimension is smaller in m^2. Thus, solar panel Sun Power 327W and inverter SMA 60 kW were selected for this research.

4.6 Total Medium Voltage Station (MVS)

MVS model SMA MVS-600-STP10 required 22 units with total price of RM 3.05 million while MVS-1200-STP10 with total price of RM 2.4 Mil based on finalized Sun Power 327W and inverter SMA 60 kW.

4.7 Simulation versus formulated calculation

Comparison between simulation versus formulated calculation were carried out for station 1 as benchmark to understand the accuracy between formulated calculation versus simulation output by referred to Sun Power SPR-E20-327-COM (08/2016) 327W solar panel and inverter SMA 60 kW. For station 1, the result showed for formulated calculation achieved total of 2288 MWh compared to simulation output 2162 MWh with 15° tilt while 2096 MWh with 10° tilt. Thus, 15° tilt from simulation showed better output and close to formulated output by delta 126 MWh. In practical, any design works, need formulated calculation or numeric methods to analyse the projected result which is "most accurate" and simulation as check-and-balance to make decision on the design and to convince approval boards on the accuracy which usually have a tolerance of +/- 10%.

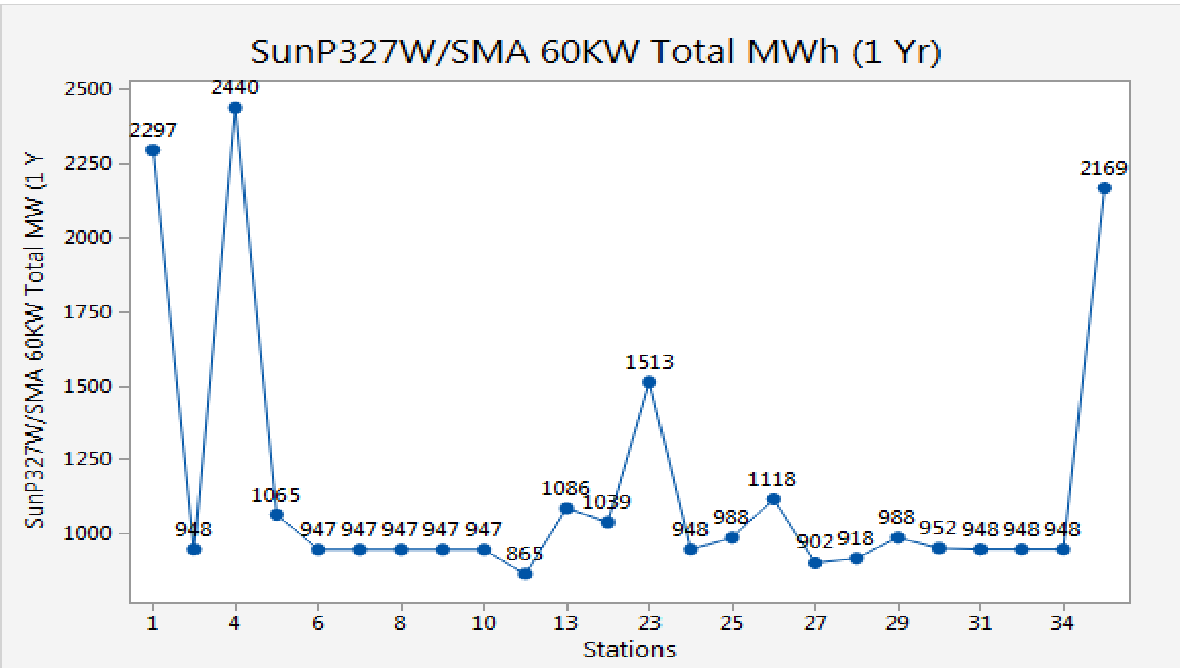

Fig. 6 – Formulated Calculation by Stations Total MWh (1 Yr)

▾ Project information

Total number of PV modules	4259	Annual energy yield	2,162.09 MWh
Peak power	1.39 MWp	Energy usability factor	97.1 %
Number of PV inverters	22	Performance ratio	75.9 %
Nominal AC power of the PV inverters	1.29 MW	Spec. energy yield	1552 kWh/kWp
AC active power	1.29 MW	Line losses (in % of PV energy)	0.41 %
Active power ratio	92.3 %	Unbalanced load	0.00 VA

▾ Information (0 warnings, 0 errors)

▾ STN 001 - SunPower 327W 15 Deg Tilt -90 Deg Azi

Fig. 7 – Simulation Results with 15° Tilted

▾ Project information

Total number of PV modules	4259	Annual energy yield	2,096.03 MWh
Peak power	1.39 MWp	Energy usability factor	98.1 %
Number of PV inverters	22	Performance ratio	77.5 %
Nominal AC power of the PV inverters	1.29 MW	Spec. energy yield	1505 kWh/kWp
AC active power	1.29 MW	Line losses (in % of PV energy)	0.39 %
Active power ratio	92.3 %	Unbalanced load	0.00 VA

▾ Information (0 warnings, 0 errors)

▾ STN 001 - SunPower 327W 10 Deg Tilt -90 Deg Azi

Fig. 8 – Simulation Results with 10° Tilted

4.8 Total MWh and Projected Revenue for 1st Year

The output of 24 stations mean (μ) by 634.9 kWh and sum is 15.24 MW were projected for 1-hour solar irradiance. A total of 27815 MWh will be generated per annum from an average solar irradiance of 5 hours per day. In this projection, we have implemented 15º tilted angle to utilise the optimum level. On the other hand, total revenue is projected to be RM 27.28 million. As shown in table 4, the break-even will be in year 7.

Table 4 – Projected Revenue and ROI

Years	FiT Range (72KW - 1MW) Rate KWH (RM) Annual Degression Rate 15%	FiT Installation in Building - Annual Degression Rate 10%	FiT Building Material - Annual Degression Rate 20%	FiT Local Produce PV Panel	FiT Local Produce Inverter	Total FiT	Total MWh. Annual Degradation 0.4% aft 5th Yr onwards	Total Revenue RM (Mil)	Loan Payment RM (Mil)	O&M Cost RM (Mil)	Total Profit RM (Mil)	ROI %
1	0.5931	0.1550	0.1325	0.05	0.05	0.9806	27815.00	27.28	12.20	0.50	14.58	114.77
2	0.5041	0.1395	0.1060	0.05	0.05	0.8496	27815.00	23.63	12.20	0.50	10.93	86.08
3	0.4285	0.1256	0.0848	0.05	0.05	0.7389	27815.00	20.55	12.20	0.50	7.85	61.82
4	0.3642	0.1130	0.0678	0.05	0.05	0.6451	27815.00	17.94	12.20	0.50	5.24	41.28
5	0.3096	0.1017	0.0543	0.05	0.05	0.5656	27815.00	15.73	12.20	0.50	3.03	23.87
6	0.2632	0.0915	0.0434	0.05	0.05	0.4981	27703.74	13.80	12.20	0.50	1.10	8.66
7	**0.2237**	**0.0824**	**0.0347**	**0.05**	**0.05**	**0.4408**	**27592.48**	**12.16**	**12.20**	**0.50**	**(0.54)**	**(0.04)**
8	0.1901	0.0741	0.0278	0.05	0.05	0.3921	27481.22	10.77	0.00	0.50	10.27	20.55
9	0.1616	0.0667	0.0222	0.05	0.05	0.3506	27369.96	9.59	0.00	0.50	9.09	18.19
10	0.1374	0.0601	0.0178	0.05	0.05	0.3152	27258.70	8.59	0.00	0.50	8.09	16.18
11	0.1168	0.0540	0.0142	0.05	0.05	0.2850	27147.44	7.74	0.00	0.50	7.24	14.48
12	0.0993	0.0486	0.0114	0.05	0.05	0.2593	27036.18	7.01	0.00	0.50	6.51	13.02
13	0.0844	0.0438	0.0091	0.05	0.05	0.2372	26924.92	6.39	0.00	0.50	5.89	11.78
14	0.0717	0.0394	0.0073	0.05	0.05	0.2184	26813.66	5.86	0.00	0.50	5.36	10.71
15	0.0610	0.0355	0.0058	0.05	0.05	0.2022	26702.40	5.40	0.00	0.50	4.90	9.80
16	0.0518	0.0319	0.0047	0.05	0.05	0.1884	26483.06	4.99	0.00	0.50	4.49	8.98
17	0.0440	0.0287	0.0037	0.05	0.05	0.1765	26479.88	4.67	0.00	0.50	4.17	8.35
18	0.0374	0.0258	0.0030	0.05	0.05	0.1663	26368.62	4.38	0.00	0.50	3.88	7.77
19	0.0318	0.0233	0.0024	0.05	0.05	0.1575	26257.36	4.13	0.00	0.50	3.63	7.27
20	0.0270	0.0209	0.0019	0.05	0.05	0.1499	26146.10	3.92	0.00	0.50	3.42	6.84
Total								**214.55**	**85.40**	**10.00**	**119.15**	**490.34**

5. Conclusion

Our main focus is to identify the best optimal solar panel and the inverter selection for minimum initial cost by maximizing the Return on Investment (ROI) for 20 years. From the projected results, Sun Power SPR-E20-327-COM (08/2016) 327W, inverter Sunny STP-60 kW and medium voltage station SMA MVS-600 kVA & 1200 kVA which theoretically and by simulation showed comparable output in terms of annual MWh. In terms of cost, initial cost of RM 76.95 million and the ROI are ranged between 114.77% to 6.84% and the profit are ranged between RM 14.58 million to 3.42 million and the ROI is highest for 1st year followed by gradual decrease subsequent years due to FIT rate and solar panel efficiency degressive. The break-even for such investment is in year 7. From the research and findings, we highly recommended MRT elevated stations as solar electricity generation for domestic usage and standalone.

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