Performance comparison of fixed and single axis tracker photovoltaic system in large scale solar power plants in Malaysia

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Article Info	ABSTRACT
	Malaysia is rapidly expanding the generation capacity of solar power through large scale solar (LSS) projects with the aim to achieve 20% renewable energy mix by 2025. This has motivated many solar industry players to explore the usage of solar PV with single axis tracker (SAT) system. However, many are still hesitant due to the lack of understanding on the comparative performance between fixed mounted solar PV with solar PV with SAT system. This paper aims to provide a comparative analysis on the performance of both systems. Simulation using PVSyst 6.83 was performed in five potential LSS sites spread across Peninsular Malaysia in Perlis, Kelantan, Pahang, Selangor and Johor with the same installed capacity of 10.32MWp. The energy yield and capacity factor for 21 years were simulated. On the average, it was found that SAT outperforms fixed mounted solar PV system by 15.08% based on their performance on their first year operation. *This is an open access article under the CC BY-SA license.*

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1. INTRODUCTION

The Malaysian government is committed to achieve 20% renewable energy capacity (RE) mix by the year 2025, with solar power being the biggest RE source. By the year 2025, it is targeted for 1.25GW of solar power to be injected to the grid, which makes up to 14% of the RE mix. To accelerate the achievement of this target, the large scale solar (LSS) scheme has been introduced in 2015 year. LSS is a competitive bidding programme to significantly lower the levelized cost of energy (LCOE) for the development of LSS photovoltaic (PV) plant [1], LSS is defined as solar photovoltaic plants each with a maximum export capacity (a.c. rating) of not less than 1 MW but not more than 100MW which consists of solar PV modules, inverters, power conditioners, switchgear, switchboards, control boards, cables, mounting structures, earthing systems, lightning protection systems, buildings, lands and the associated ancillary systems such as electrical and mechanical installations, compound lighting, security surveillance systems. Unlike several predating schemes such as feed in tariff (FiT) and net energy metering (NEM), LSS was placed directly under the purview of the Energy Commission which strongly signifies the level of commitment of the Malaysian government towards its sustainable energy goal.

The identification of sites for the deployment of solar system is crucial. Various methodologies have been explored in several countries including Turkey [2, 3], Spain [4], Iran [5, 6], Indonesia [7], Saudi Arabia [8], Morocco [9], India [10], Serbia [11], and Afghanistan [12], In Malaysia, information on which systematic approach to be used for the selection of sites for solar farm is still severely lacking in the literature.

Another equally crucial stage involved in the deployment of solar farms is the selection of PV system technology. In general, PV system can be either a fixed or a tracking system [13]. The single axis tracker (SAT) system can be further divided into two categories namely horizontal single-axis or vertical single-axis systems [14] and dual tracker system [15]. The attractiveness of these technologies have gradually increased due to the increasing affordability of solar energy technologies.

Fixed mounted solar PV is the most widely deployed solar PV system in the world largely due to its lower cost despite its lower energy yield as compared to SAT. SAT is a technique to track the sun from one side to another [16]. SAT system is not widely used in Malaysia although it gives more energy than the fixed structure [17]. SAT can be either east-west tracker which follows the sun east-west, but it is fixed in the site on the north-south direction, while north-south tracker follows the sun north-south but it is fixed in the site on the east-west direction [18]. Numerous studies comparing the performance of fixed and tracker system in terms of capacity factor and specific yield have been done in Egypt [19], Germany [20], Italy [21], South Africa [22], USA [23, 24], Thailand [25], India [26-29], China [30-31], Turkey [32], Saudi Arabia [33], Brazil [34], southern Europe [35] Germany [36], Nigeria [37], Jordan [38], Tunisia [39] and Estonia [40]. All of the aforementioned studies concluded that SAT performs 12%-40% better than fixed system. However, no study has been done on implementation of such systems at large scale i.e. more than 10 MW which will be considered in this paper.

Since the launch of LSS, the response and acceptance amongst private industries has been overwhelming. Many of them has been motivated to explore on the application of SAT as compared to the conventional fixed mounted solar PV system with the belief that the former technology performs better than the latter technology. However, many of the solar industry players remains hesitant to invest and adopt SAT technology due to the vacuum in the information on the comparative performance of both technologies being deployed in Malaysia. It is therefore the prime motivation of this study which is to evaluate the performance of both of the aforementioned technologies in terms of energy yield and capacity factor. The evaluation will be performed using the widely adopted approach of simulation via PVsyst. The simulation outcomes shall serve as important guide for future deployment of SAT solar PV systems in Malaysia.

In this paper, the research methodology will be described first. Determination of the required simulation parameters will be explained. Then, the simulation results which include specific yield (SY), annual energy production (AEP) and capacity factor (CF) of fixed system with vs Single Axis Tracker will be presented and analysed.

2. RESEARCH METHOD

Figure 1 shows the overall flow of methodology employed for this study. Firstly, the identification process of LSS sites considered in this study will be explained. Then, the configuration of the system for simulation will be outlined. Next, system losses will be evaluated. Finally, the specific yield (SY) and average energy production (AEP) will be computed.
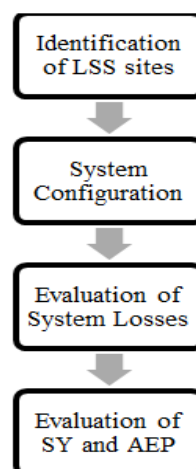
Identification
of LSS sites

↓

System
Configuration

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Evaluation of
System Losses

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Evaluation of
SY and AEP

Figure 1. Project flow chart

2.1. Identification of LSS sites

Five sites spread across Peninsular Malaysia have been identified for this study as summarized in Table 1. These states are selected as they are potential LSS sites. The states are also evenly distributed across Peninsular Malaysia with Perlis and Kelantan (Northern region), Selangor (Central region), Pahang (Eastern region) and Johor (Southern region).

The meteorological data of solar radiation, diffuse radiation, wind speed and ambient temperature are obtained from the PVsyst database Meteonorm 7.2. Meteonorm applies interpolation between weather stations, and a limited weighting on satellite imagery data to estimate irradiance parameters with a low density of available ground based data. Table 1 shows the solar radiation data for all five LSS sites. The global horizontal radiation (GlobHor) and the ambient temperature (T_Amb) are the same for both fixed and tracker. However, the difference is in the global incident in collector plane (GlobInc) which is caused by the tracker system as shown in Table 1. The tilt angle of the PV fixed mounted structure in all five sites is set to 8° while the azimuth is set to zero which is facing south to get the maximum gain in solar irradiance from the sun. In short, this leads to optimum amount of energy produced from the system. On the other hand, the axis tilt and azimuth are both set to zero for single axis tracker (SAT) system. The minimum and maximum rotation angle (Φ) are -45° and 45° respectively. All of these aforementioned factors affect the GlobHor for both fixed and SAT system. In terms of optical losses which is dependent on the incident angle modifier (IAM) phenomenon, the incidence loss (reflections due to the Fresnel's laws) is sufficiently well defined by a parameterization proposed by "Ashrae" (US standards office) [41]. It is also known as irradiance after reflection.

One of the major challenges in designing solar farm is to avoid shading loss while taking into consideration the land area constraint. The shading loss is due to the structure of array and the tilt of the solar panels. Another loss factor is the soiling loss. To get the optimum performance, the solar panels should be kept clean throughout its operational years to ensure that the solar irradiance is hitting the panel without being affected by dust the which can significantly reduce the efficiency. The effective global irradiance (GlobEff) will eventually be computed by taking into consideration all of the aforementioned irradiance loss factors.

Table 1. Potential LSS sites considered in this study

LSS Sites	Geographical Location	Altitude	GlobHor (kWh/m²)	GlobInc (kWh/m²) Fixed	GlobInc (kWh/m²) Tracker	GlobEff (kWh/m²) Fixed	GlobEff (kWh/m²) Tracker	Temperature
Perlis	6.60 ºN, 100.19 ºE	75.5m	1805	1812.7	2153.3	1742.4	2059.8	25.13
Kelantan	5.84 ºN, 102.42 ºE	27.6m	1717.5	1716.1	2015.7	1646.1	1919.2	27.16
Pahang	1.66 ºN, 103.72 ºE	17.8m	1664.6	1659.2	1944.8	1590.5	1850.7	26.79
Selangor	2.71 ºN, 101.48 ºE	18.5m	1612.2	1606.1	1859.6	1538.9	1764.9	27.6
Johor	3.43 ºN, 102.75 ºE	14.6m	1626.1	1623.5	1890.3	1599.2	1798.3	26.21

2.2. System configuration

The LSS PV-Grid system considered in the scope of this study consists of solar PV modules, inverters, transformer, switchgear, cables, mounting structures, earthing system, and lightning protection system [42]. The system has 10.32MWp DC installed capacity with 10.31MWa.c. AC capacity. The simulation and analysis was carried out using PVsyst 6.83, PVsyst is a software for studying, simulation, and data analysis of PV systems. It is required from ST for all LSS bidder to perform this simulation by using similar tools to evaluate and declare the monthly and annual energy exported by each LSS plant [43].

The plant in all five sites consists of 800 strings with each string having 30 panels connected in series. Each of these string is connected in parallel with other string to eventually form an array. Each solar panel has a rated power of 430Wp. There are mainly two types of inverters for solar plants namely central inverter and string inverter. Central inverter is commonly used for large solar system (LSS) due to its cost effectiveness while string inverter is commonly used for rooftop installation. The DC power produced from each solar string runs along cables to the combiner boxes where they are connected in parallel with other strings. From there, the DC power goes into the central inverter and converted to AC power. Central inverter units are physically much larger than string inverters. The plant consists of 3 units of central inverter with rated power 3437 kVA at ambient temperature 45°C. The central inverters are then connected to their respective transformer to step up from low voltage to medium voltage (33 kV). Finally, the voltage is further stepped up to 132 kV before being injected to the grid. Figure 2 illustrates the single line diagram of the system under study. Note that the same configuration is applied for both fixed and SAT plant in all five sites. To the best knowledge of the authors, the performance study at the LSS scale is yet to be done in Malaysia. Most, if not all, of the recent studies are focused on solar systems of much smaller capacity with rating from 20 Wp-7.98 kWp only [17-37]. Table 2 summarised the characteristics of the PV modules and central inverter used in this study.

Table 2. Electrical properties of PV module and central inverter

| PV Module		Central Inverter	
Test Condition	STC	Maximum PV input voltage (V)	1500
Maximum power (Pmax) (W)	430	MPP voltage range for nominal power (V)	875-1300
Open Circuit Voltage (Voc) (V)	49.2	Number of independent MPP	1
MPP Voltage (Vmpp) (V)	40.6	Maximum PV input current (A)	4178
Short Circuit Current (Isc) (A)	11.19	Nominal AC output power (KVA)	3437 @45oC
MPP Current (Impp) (A)	10.6	Nominal grid frequency (Hz)	50/45-55
Cell Properties	Monocrystalline	Efficiency	99%
Standards	IEC61215, IEC61730	Transformer rated power (KVA)	3437
		Nominal grid frequency (Hz)	50/45-55
		LV / MV	0.6 kV / 10-35
		Standards	IEC 61727, IEC 62116
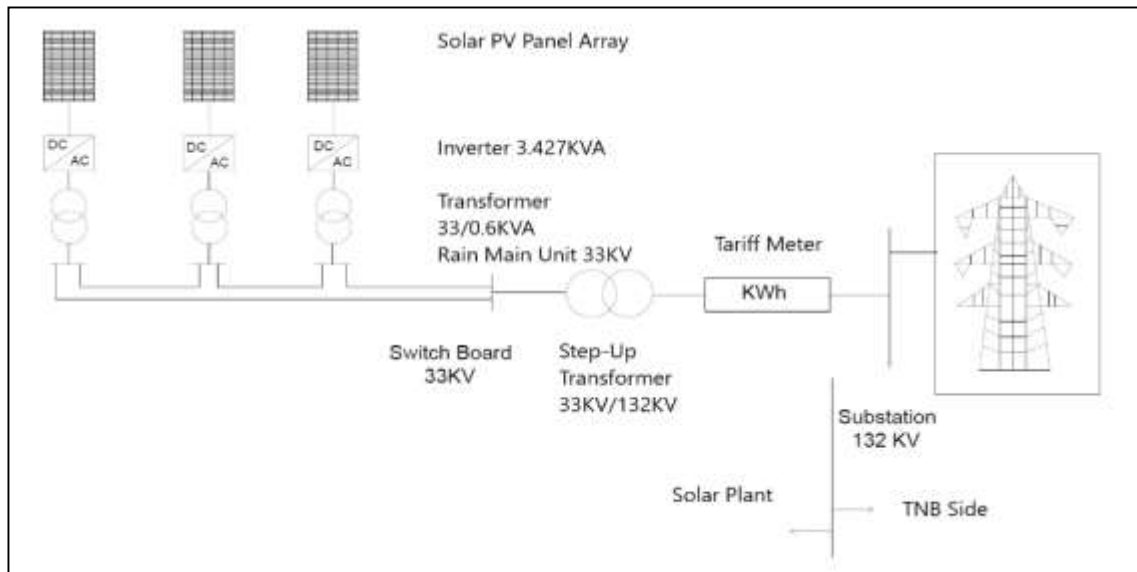
Figure 2. Schematic of the system

2.3. Evaluation of system losses

System loss consists of PV losses due to irradiance level and temperature level under standard test conditions (STC), PV module quality loss, light induced degradation (LID) loss and ohmic wire loss. Other contributor to system losses includes inverter efficiency which is directly affected by the ambient temperature at the site and the distance between the inverter and the transformer. In this study, central inverter in which both the inverter and the transformer are contained in the same box is used. Transformer loss is also considered.

2.4. Evaluation of specific yield (SY) and average energy production (AEP)

Once the evaluation of the system losses is completed, the specific yield (SY) and annual energy production (AEP) can then be computed. SY is defined as the annual net a.c. Export Energy of the PV System of the LSS Plant per kWp installed (kWh/kWp/year). Meanwhile, AEP is defined as the maximum a.c. rated capacity of the Large Scale Solar Plant supplying power to the Utility Power System measured at the Interconnection Point. The simulation will be performed for up to 21 years, which is the required period set by the local utility tenaga nasional berhad (TNB) and solar power purchase agreement (SPPA) in Malaysia.

3. RESULTS AND DISCUSSION

This present work aims to quantify the difference of a Specific Yield (SY), Annual Energy Production (AEP) and Capacity Factor (CF) of fixed system with vs Single Axis Tracker.

3.1. Specific yield of fixed vs single axis tracker (SY)

Table 3 shows the SY (kWh/kWp/year) of both fixed and SAT system at first year of operation. It can be clearly seen that the SY of SAT system is significantly higher than the SY of fixed system. This can be attributed to the role of the tracker in the SAT system which is able to maximize the amount of solar irradiation

received by the panel. The highest difference in terms of percentage is in state Perlis which is 16.55% and this could be due to the high solar irradiance of 1805 kWh/m2 at this site as shown in Table 1.

3.2. Annual energy production of fixed vs single axis tracker (AEP)

Table 3 also shows the AEP (MWh/year) of both fixed and SAT system. The AEP depends directly on SY and installed DC system size on the solar plant. Similar trend with the results in Table 3 can be observed with the highest percentage difference being in Perlis. On the average, there is a 15% improvement that SAT has over fixed systems. This falls in the range of 12%-40% improvement reported in the literature [19-40]. However, it has to be emphasized again that this is one of the first studies on the implementation of SAT in a large scale solar system manner.

Table 3. SY and AEP of fixed and tracker PV plant at first year operation

State	SY		Difference (%)	AEP		Difference (%)
	Fixed	SAT		Fixed	SAT	
Perlis	1480	1725	16.55%	1480	1725	16.55%
Kelantan	1397	1620	15.96%	1397	1620	15.96%
Johor	1363	1566	14.89%	1363	1566	14.89%
Selangor	1311	1491	13.73%	1311	1491	13.73%
Pahang	1336	1525	14.15%	1336	1525	14.15%

3.3. Capacity factor (CF) of fixed vs single axis tracker (SAT)

The Capacity factor of PV system expressed as percentage is normally defined as the ratio of AEP over the product of DC installed capacity and the total number of hours in a year (8760 hours). One of the requirements needed to be fulfilled is to achieve the capacity factor needed for every certain year [43]. The capacity factor is expected to decrease every year due to the degradation of the solar panel every year. As shown in Figure 2, Perlis exhibits the highest capacity factor due to its highest AEP value as shown in Table 3 previously. Figure 3 shows the comparison of CF over a period of 21 years as required in the SPPA [43] for both systems in Perlis. Similar trend is exhibited in Kelantan, Johor, Selangor and Pahang. It is worth mentioning that PV module manufacturer usually provides a warranty of up to 25 years and guarantees the performance starting from first year initial degradation to 98% and 0.55% after first year operation.
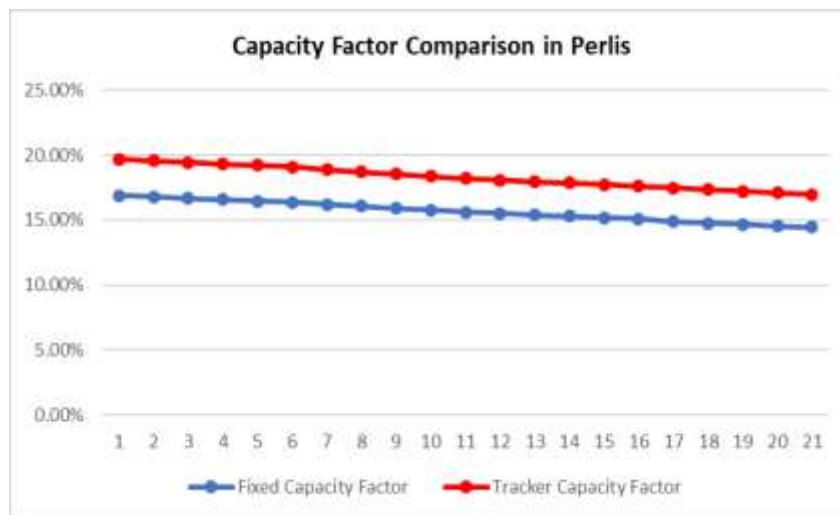

Figure 3. CF comparison between fixed and SAT in Perlis

Table 4 shows the CF of both fixed and SAT system at first year of operation for all five sites. It can be clearly seen that the CF of SAT system is significantly higher than the CF of fixed system. This is again due to the role of the SAT system as explained in previous section.

With this as backdrop, the interest towards SAT system should be propelled as Malaysia will continue to encourage deployment of more solar plants due to lack of potential of other renewable energy resources such as wind in Malaysia [44].

Table 4. CF of fixed and tracker PV plant at first year operation

State	CF for Fixed Technology	CF for Tracker Technology	Percentage difference
Perlis	16.89%	19.70%	2.81%
Kelantan	15.95%	18.50%	2.55%
Johor	15.56%	17.88%	2.32%
Selangor	14.96%	17.02%	2.06%
Pahang	15.25%	17.41%	2.16%

4. CONCLUSION

The strong push for the development of large scale solar PV system in Malaysia has prompted a surge in interest towards adopting and implementing the SAT system. This paper has concretely affirmed via simulation studies that the SAT system yields about 15% more energy than the conventional fixed mounted system when being implemented across Peninsular Malaysia at a large scale manner. The difference appears to be stable across Peninsular Malaysia due to a relatively strong degree of homogeneity in the meteorological condition of the five states. Similarly, the trend in the variation of capacity factor over a period of 21 years is also consistent throughout the five sites considered. However, future research on the cost effectiveness of SAT is warranted to complement the technical findings presented in this paper.

ACKNOWLEDGEMENTS

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