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Power System Analysis for Large Scale Solar Photovoltaic System using PVSyst and ETAP

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Abstract: Renewable energy (RE) field has been listed as one of the alternative energy solutions for the global energy transition to zero-carbon energy generation by 2050. This is because Malaysia has benefited from the exploration of the country's potential for Large Scale Solar Photovoltaic (LSS PV) installations. However, LSS often faced technical challenges in the LSS PV to the power grid integration. The technical challenges can be classified as voltage instability, reactive power regulation, and short circuit power deviations. In this project, the two methods are used which are PVSyst and ETAP software. The aims of this project are to design a Grid Connected Photovoltaic system using PVSyst simulation and analyze the power system network for the transmission connected LSS plant to the grid system using ETAP software and investigate the performance of grid connection to be able to comply with Grid Code requirements. The PVSyst simulation result showed that the system is able to produce a 41 to 42 MW capacity of AC rating using three different PV modules. By using the output rating from the PVSyst, the PV system is then integrated into Bus 7 where the findings of this project found that the deviations in bus voltages were minimal and the network was able to operate within the specified limits.

Keywords: Renewable Energy, Large Scale Solar, Photovoltaic, Malaysian Grid Code

1. Introduction

Renewable energy (RE) has been listed as one of the alternative energy solutions for the global energy transition to the generation of carbon-free energy by 2050 [1]. As a result, Malaysia's equatorial location has benefited the exploration of the country's potential for large-scale solar photovoltaic (LSS PV) installations. When compared to other renewable energy sources, solar electricity is the most preferred RE source in Malaysia [2]. Hence, LSS can be viewed as a transparent mechanism in order to achieve the government's RE target in which solar PV energy harvesting can be done through a grid-connected via LSS PV [3]. According to Suruhanjaya Tenaga, LSS refers to any solar photovoltaic plant

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in Peninsular Malaysia, Sabah, or Labuan with a capacity that is permitted by The Energy Commission and connected to either the Transmission Network for less than 30 MW or Distribution Network for more than 30 MW [4]. The specifications for the grid-connected photovoltaic model are presented in MS: 1837 by the Malaysian Standards Department in which the paper contains the specifications for the electronic components used in the grid-connected system. Malaysian Standards MS: 1837 also discussed the characteristics of PV arrays such as DC vs AC behavior, series-parallel configuration, low fault levels and operating temperature [5]. Researchers discovered that the cost of producing PV panels is steadily reducing due to advancements in material and PV array manufacture technology and that solar power generation will soon be competitive with other kinds of renewable energy. PV arrays in Grid-Connected Photovoltaic (GCPV) 2 systems, on the other hand, tend to be low voltage due to low solar cell conversion efficiency and the fact that a PV array's output power is affected by irradiance and temperature. Thus, maximum power point tracking (MPPT) circuitry and the selection of inverter modules that utilize the MPPT should be used to operate the PV array fully [6].

Researchers also have classified some technical challenges faced in the LSS PV grid integration such as voltage unbalance and fluctuations, reactive power control, short circuit power variations and power system instability. According to Mohanan et al. (2020), a power system is a nonlinear network that differs constantly depending on several parameters such as key operating specifications, transmission parameters and generator outputs [2]. The stability of a power system can be divided into three categories like steady and transient state as well as dynamic stability. Meanwhile, fault or disturbance can cause the entire system or part of the system to fail to range from short to long timescales as measured in time is known as an unstable state system. Similar studies addressing the same concern of environmental characteristics such as temperature, wind and irradiance that resulted in the variations of the energy profile were undertaken for determining the LSS PV to the power system.

Since researchers found out an ideal bus for LSS integration can lead to a stable power system, a number of methods for dealing with the power system instability have been proposed. Power system stability can be addressed by connecting the FACTS device to boost the bus voltage on transmission lines and reactive power correction was necessary to improve network performance. Researchers also stated that determining the configuration of devices such as synchronous machines, capacitor banks, and other reactive power injections is made possible in order to place it in the proper position or bus. The proposed solutions were tested on IEEE 9- Bus and IEEE 28- Bus test systems. The above reviews also looked at the level of penetration required to keep the transmission system stable while using various PV modules [1],[2],6]. A study from India also provides the impacts of LSS PV penetration into the IEEE 39- Bus test system to address the same problems [7].

Hence, the objective of this paper is to design the grid-connected photovoltaic large-scale system using PVSyst simulation, to analyze the power system network for the transmission-connected Large Scale Solar plant to the Grid System during steady state using ETAP software and to investigate the stability of the grid-connected Large Scale Solar plant in the network system to comply with Grid Code requirements. The findings should give a major contribution to the field of LSS PV grid integration where in this research, monocrystalline, polycrystalline and thin film will be used to design the grid-connected system and the power system network will be utilized by the IEEE-10 Bus system, which will provide insights on the power flow analysis and stability of the system.

2. Materials and Methods

This section outlines the methods used in this study which included the PVSyst simulation and ETAP modeling for Large Scale Solar Photovoltaic grid integration in which the methods offer steady-state analysis and detailed assessment of the interconnection between the Large Scale Solar plant and the grid-connected Photovoltaic system to comply with Malaysian Grid Code.

2.1 Feasibility and generation profile of Solar PV power plant

The main stages for determining the maximum energy yield yearly and its performance ratio are site inspection and decision, environmental evaluation, and shading analysis. Land availability, yearly yield and transmission losses are the three key criteria that go into choosing a location for LSS PV.

2.1.1 Decision on site

Malaysia receives a large amount of solar energy as a country that is located in a tropical region with high levels of heat, making it a perfect location to install LSS PV. The country receives annual irradiation of 1900 $kWh\ m{-}2$ [2]. The features of the site location chosen for the LSS PV installation is one of the key aspects that can influence and affect the system's total energy output. The Malaysian government's EC has identified a number of locations in Malaysia that are appropriate for LSS PV deployment. One of the Energy Commission's announced sites is considered to provide realistic results in this study which is a 50 MW capacity grid connected LSS PV at Tanjung Malim, Perak which falls under the jurisdiction of the Consortium Malakoff Corporation Bhd and DRB-HICOM Environmental Services Sdn Bhd [8].

2.1.2 Solar irradiation and yearly energy yield

The intensity of solar irradiation received by the PV panel determines the amount of electrical power produced by the grid-connected Photovoltaic [9]. When the level of power penetration into the grid increased, the voltage and frequency stability increased. This study is limited to the yearly energy yield and sun irradiation at Tanjung Malim, Perak as the nearest station for meteonorm data was located at Tanjung Malim. As the meteonorm data for Tanjung Malim was not available in the database, the irradiation values were generated by the PVSyst software. The monthly Global Horizontal Irradiation (GHI) was tabulated and the yearly GHI was 1722 $kWh\ m{-}2$.

2.1.3 Power network and infrastructure

When transmission losses are limited, the generated energy can be used to its maximum capacity. The approach can be accomplished by transmitting electricity over a shorter distance from the generating plant to the distribution network rather than a longer distance. Since long-distance transmission can result in increased losses, especially in AC transmission as the transmission line's impedance value of 26 is important. Because of the availability of a reliable transmission and distribution network in Perak, LSS PV installation has the advantage to produce maximum utilization of energy [11].

2.2 Feasibility and generation profile of Solar PV power plant

The PV modules chosen for the assessment include three different types of PV modules which are monocrystalline, polycrystalline and thin film PV that was available on the basis of local availability in Malaysia such as First Solar, Jinko Solar and Longi Solar.

2.3 Design of GCPV system using PVSyst

PVSyst is used to generate real-time measurements and data for the chosen PV modules, with the project design feature of the software being primarily used for grid-connected system simulation. The meteo file for Tanjung Malim is generated by using Perak as base data since PVSyst database only provides a few meteorological station data for geographic regions. Once the meteo file is exported and then deployed for further assessment by selecting three different types of PV modules for the assessment that includes monocrystalline, polycrystalline and thin film PV whereas inverter data used for this paper is the centralized inverter.

2.4 Modelling using ETAP

It is difficult to extract the real data of the Malaysian grid and at the same time, the data would be confidential. Therefore, a test system derived by IEEE is used to evaluate the solar PV systems using the PVSyst generation profile. By using the AC rating of the inverter output, it is then fed into the ETAP to simulate the load flow analysis with a major focus on the voltage level variation in the buses by integrating the LSS plant into the grid system.

2.4.1 IEEE 10-Bus design

The standard IEEE-10 Bus test system adopted for this study is 10 Bus and consists of 4 generators, 5 loads, and 10 buses. The base KV levels are 33, 275 and 132 kV.

2.4.2 Integration of Solar PV with IEEE 10-Bus system design

A solar PV with a generation capacity will be used as the generation power in the LSS plant machine data by using the AC inverter output value from the PVSyst simulation. The peak capacity of the generation was limited to 50 MW with a base voltage of 33 kV. The research was carried out to study the configuration model for the grid integration of Solar PV bus with the IEEE-10 Bus test system. The solar PV bus was interconnected to Bus 7 where the setup was configured by connecting the solar PV to Bus 7 of the IEEE-10 Bus system using a step-up transformer. The transformer steps up the voltage level to 132 kV for interconnection to Bus 7.

2.5 Simulation using ETAP

ETAP is an analytical engineering software that is helpful in simulating and analyzing the steady state and dynamic power system that can be used in many sectors which includes generation, transmission and distribution. The simulation assessment was carried out for steady state analysis where the properties of LSS generator in steady state is similar with the conventional generator as it can be 34 modeled as wind generator which the active and reactive power limit can be set to maximum and minimum in the ETAP power flow case [10]. The power flow of the system is tested and then analyzed for the interconnection between the LSS plant and grid system which involves load flow, short circuit, stability and sensitivity, optimal power flow and contingency analysis. The analysis was done by integrating the solar PV Bus to the Bus 7 on the IEEE-10 Bus test system using the three different AC ratings from the inverter output of the PV module.

2.6 Performance evaluation

Malaysian Grid Code will be used to evaluate the performance of the integration between the LSS plant to the grid system. The LSS PV grid integration shall be able to comply with the Grid Code requirements by comparing the performance and ability of the LSS PV grid to integrate with the technical assessments as summarized in Table 1.

Table 1: Technical requirements in Grid Code [12]

No.	PSS Scope of Studies	Criteria to Benchmark
1	Power flow and Contingency Analysis	• No branch overload. • Voltage variation within $\pm$5%.
2	Reactive Power Requirements	• The LSS plant shall be able to deliver the reactive power requirements within the power factor limits of 0.85 lagging to 0.95 leading at 20% output to 100% output as shown in Figure 2.4. • The reactive power output under steady state conditions that is measured at PCC should be fully available within the range

		±10% at 132 kV as shown in Figure 2.5.
3	Short Circuit Analysis	• Short circuit rating at 132 kV buses shall not exceed 31.5 kA (rms). • Short circuit rating at 33 kV buses shall not exceed 25 kA (rms).

3. Results and Discussion

This chapter presents the outcomes data and analysis of the study which consists of two parts that are simulation using PVSyst and an analysis using ETAP where four different analyses are simulated.

3.1 Simulation using PVSyst

The maximum yield is obtained in March while the minimum yield is received in December. Despite the higher energy generation by First Solar due to the high rating of PV modules, thin film technology incorporates Cadmium Telluride (CdTe) which poses a potential risk to the environment. However, the advantage of using thin film is that they required a smaller number of modules to generate 50 MW grid-connected compared to the other models. Meanwhile, the performance characteristics and efficiency of monocrystalline and polycrystalline PV modules are comparable although monocrystalline PV modules rating is higher than polycrystalline. This is mainly because of the slight in losses under the threshold voltage of the inverter as the number of PV modules in series is not enough. The total active energy injected into the grid per month for a duration of one year is illustrated in Figure 4.2. Based on the graph, First Solar FS-6460-PA proves to be the best module that generates maximum energy to the grid at 42.4 GWh per year followed by Jinko Solar JKM 345PP-72-DV and Longi Solar LR4-72 HPH 460 M G2 which injects 42.1 GWh and 41.9 GWh per year respectively.

3.2 Modelling using ETAP

3.2.1 Modelling of IEEE 10-Bus

In overall design, Bus 2 (40 MW, 25 MVAR), Bus 3 (68 MW, 24 41 MVAR), Bus 6 (11 MW, 3 MVAR), Bus 7 (17 MW, 5 MVAR), Bus 8 (0 MW, -39 MVAR) and Bus 10 (20 MW, 9 MVAR) are the load buses as illustrated in Figure 1 in the Appendix section.

3.2.2 Load flow analysis

The load flow analysis result shows the percentage of potential difference variation during solar PV penetration where solar PV is integrated into Bus 7. The load flow analysis for integrating all three LSS PVs to the IEEE 10-Bus power system shows a similar response as the magnitude of AC rating energy injected ranges between 41 and 42 MW and the behavior is similar. When the LSS PV is integrated to IEEE 10- Bus system at Bus 7, it can be observed that there is a very slight fluctuation in voltage 42 stability in the buses as there is mostly an increase in voltage. However, the fluctuations are not too large and are within limits. The results for a load flow analysis of all buses during the steady state are tabulated in Table 2. The voltage levels on all buses can be seen to remain steady with a slight drop in voltage where the voltage limits are between ± 6 %. Yet, 10 BMSH132 bus is seen to experience the most voltage drop during the load flow. Nevertheless, the bus still can operate well within the desired limits.

Table 2: Percentage of steady state voltage drop during normal operating condition

Location	System voltage (kV)	Percentage of voltage drop (%)
1_KTNN275	275	0
2_KTNN132	132	1.09
3_KTAN132	132	2.87
4_KAWAA132	132	2.87
5_MECC132	132	2.87
6_PKN132	132	5.62
7_PKAN132	132	6.09
8_TAPG132	132	6.49
9_TBJU132	132	6.84
10_BMSH132	132	7.62
LSS	33	0

3.2.3 Short circuit analysis

In short circuit analysis, the depicted results show the initial symmetrical rms short circuit current, I and peak short circuit current, I peak readings at all buses when the fault is placed on all 132 kV buses as shown in Table 3. From the values, it can be concluded from the current rating that no overcurrent occurs in the power system network as the short circuit rating at 132 kV buses has not exceeded31.5 kA (rms). However, the LSS bus recorded a value of higher than 25 kA (rms) though there is no alert view in the display options that suggest the 33 kV bus is overcurrent.

Table 3: Initial Symmetrical Rms Short Circuit Current, I And Peak Short Circuit Current, I Peak at All Buses

Equipment	**Voltage (kV)**	**3-phase fault**		**Line ground fault**	
		Initial Irms (kA)	**Initial Ipeak (kA)**	**Initial Irms (kA)**	**Initial Ipeak (kA)**
1_KTNN275	275	20.097	53.71	22.067	0
2_KTNN132	275	20.162	51.289	18.373	0
3_KTAN132	132	13.818	30.826	8.185	0
4_KAWAA132	132	10.666	25.629	9.891	0
5_MECC132	132	8.283	16.916	4.679	0
6_PKN132	132	11.501	25.246	5.712	0
7_PKAN132	132	9.701	21.244	4.574	0
8_TAPG132	132	8.688	18.752	4.812	0
9_TBJU132	132	17.779	42.744	13.61	0
10_BMSH132	132	6.551	14.212	3.485	0
LSS	33	1560.7	3853.7	549.93	0

3.2.4 Stability and sensitivity analysis

Table 4 shows the percentage of stability at all buses involved. It can be said that there is no weak buses in the power system network as all buses recorded 100% of stability which indicates the status of voltage stability.

Table 4: Percentage of Stability at All Buses

Location	System voltage (kV)	Percentage of stability (%)
1_KTNN275	275	100
2_KTNN132	132	100
3_KTAN132	132	100

4_KAWAA132	132	100
5_MECC132	132	100
6_PKN132	132	100
7_PKAN132	132	100
8_TAPG132	132	100
9_TBJU132	132	100
10_BMSH132	132	100
LSS	33	100

3.2.5 Contingency analysis

For contingency analysis, the simulation was performed when LSS Bus is interconnected to the 7_PKAN132 Bus where the voltage deviations were visible on all buses. The integration of the LSS bus to Bus 7 showed negligible voltage rises in the 1_KTNN275 bus while voltage drops in the remaining bus which is not within the specified normal operating limits that are ±5% and ±6%. The impact on the buses can be seen as shown in Table 5 accordingly. Since Bus 2, Bus 3, Bus 6, Bus 7, Bus 8 and Bus 10 are the load buses, it is important to mitigate these violations to transfer the maximum active power. Hence, the integration of a Solar PV bus for this configuration is recommended to implement additional power electronics such as a reactive power compensator.

Table 5: Bus voltage

Location	System voltage (kV)	Voltage
1_KTNN275	275	158.8
2_KTNN132	132	73.13
3_KTAN132	132	71.73
4_KAWAA132	132	71.73
5_MECC132	132	71.73
6_PKN132	132	69.58
7_PKAN132	132	69.22
8_TAPG132	132	68.02
9_TBJU132	132	68.64
10_BMSH132	132	68.02
LSS	33	19.05

4. Conclusion

This paper proposed a design of the Grid Connected Photovoltaic Large Scale System using PVSyst simulation where the system performance is assessed using three different types of PV modules. The AC rating of the inverter output obtained was found to be higher for the thin film PV module by First Solar with a value of 42.4 GWh generated per year. In addition, the number of modules required to generate a 50 MW capacity of grid-connected was considerably lesser when compared to monocrystalline and polycrystalline PV modules. Yet, in terms of environmental aspects, monocrystalline and polycrystalline are better than thin-film modules as the module used CdTe. Other than that, although monocrystalline PV module has a higher rating than polycrystalline, the performance however was comparable as it is evident that Jinko Solar and Longi Solar generated almost similar energy per year. In addition, this paper provided four different analyses of voltage stability by analyzing the power system network for the transmission-connected Large Scale Solar plant to the Grid System during steady state using ETAP software. The findings of this paper found that the integration of the Solar PV bus to Bus 7 showed to be the best configuration because the deviations in bus voltages were minimal and the network was able to operate within the specified limits. This paper also investigated the stability of the grid-connected Large Scale Solar plant in the network system to comply with

Malaysian Grid Code requirements where the outcomes obtained from this paper showed that reactive power such as FACTS devices is needed to improve the performance of the bus voltages.

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Appendix A (Optional)

The IEEE 10-Bus model that is utilized in ETAP simulation is illustrated in Figure 1.

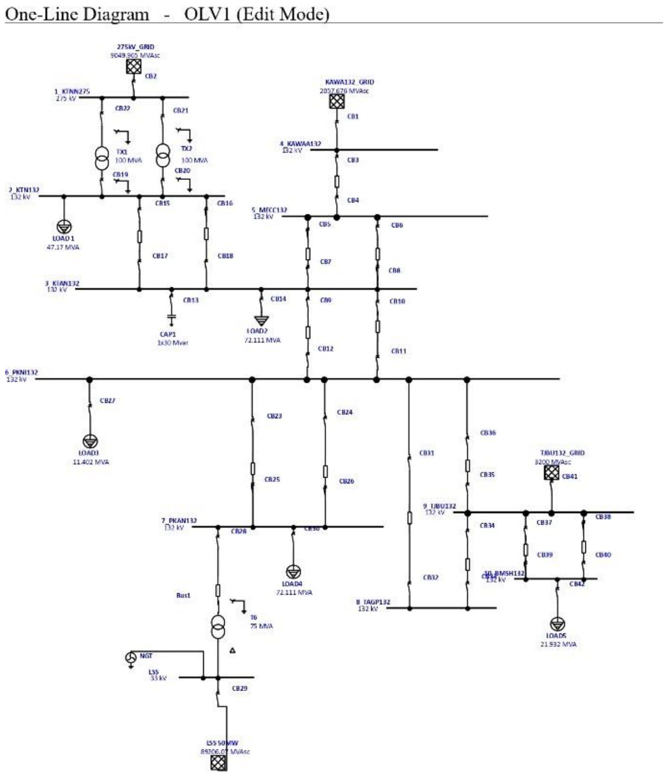

Figure 1: IEEE 10-Bus model

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