SASEC2015
Third Southern African Solar Energy Conference
11 – 13 May 2015
Kruger National Park, South Africa

DEVELOPING A SUSTAINABLE UTILITY-SCALE SOLAR FRAMEWORK IN MALAYSIA

N.Z. Mohd Zamin*, K.A.F Jamil, A.F. Abd Jamil and Joon b. Ibrahim
*Author for correspondence
Single Buyer Department,
Tenaga Nasional Berhad,
129 Jalan Bangsar, 59200,
Bangsar, Malaysia
E-mail: zafinamz@tnb.com.my

ABSTRACT

Malaysia is set to increase its solar energy utilisation as the first utility-scale solar project in the country is currently in the works. Accordingly, the national framework for utility-scale solar is currently being formulated in anticipation of more large scale solar generators connecting to the Grid.

Meanwhile, in some countries, overly-ambitious renewable programmes have been modified or scaled-down. Most of these power systems have discovered that there is a limit on how much variable energy resources (VERsto) that the Grid can accommodate before major reinforcements need to be made in order to maintain grid reliability. Learning from international experiences, a sustainable and transparent policy is crucial in order to ensure smooth adoption of renewable energy (RE), especially more so in a vertically-integrated environment such as Malaysia.

In this study, the impact of utility-scale solar penetration on the Peninsular Malaysia total generation system cost in the year 2020 was evaluated. An economic approach was adopted, in which the generation system differential cost and fuel off-take as a function of solar penetration level were analysed using PLEXOS simulation software. A background on the utility-scale solar landscape in Malaysia is also presented. The results point to a much higher penetration level than predicted, in the range of 600 to 2200 MW. It was also discovered that, at higher penetration levels, coal generation will be significantly affected by utility-scale solar integration.

INTRODUCTION

Although Malaysia lies in the equatorial region, application of solar energy in power systems is still considered to be at the infancy stage, as compared to other developing countries. Even though the introduction of FiT back in 2011 managed to boost the utilisation of solar energy in its power system, Malaysia unfortunately slightly missed the target in achieving its national renewable target of 5.5% share in the energy mix by 2015.

The successful power purchase agreement (PPA) negotiations of Malaysia's first utility-scale solar plant marks an important milestone, and is expected to drive significant additional development of utility-scale solar in the future. In order to ensure smooth adoption of solar energy into Malaysia's energy mix, the Ministry of Energy, Green Technology and Water of Malaysia (KeTTHA) with the assistance of the Sustainable Energy Development Authority (SEDA) are currently drafting the first utility-scale solar policy.

While meeting the renewable target remains an important national agenda, the technical and economic impact of high solar penetration into the Grid must be fully understood. High penetration levels of renewable energy (RE) coupled with unsustainable policies have resulted in compromised grid reliability and significant tariff hikes in some countries. As a result, some jurisdictions have now enforced significant downward adjustments on their overly generous and unsustainable renewable subsidy schemes [1,2], while some renewable portfolios have been completely suspended [3].

OBJECTIVE

The Single Buyer of Malaysia, the entity responsible for securing long-term generation capacity at least cost for the Malaysian electricity supply industry (MESI) [4], is taking proactive steps to evaluate the economic impact of utility-scale solar penetration on the grid system. This paper attempts to determine the optimum penetration level of utility-scale solar in Malaysia's energy mix in year 2020, based on the impact to the total generation system cost.

SCOPE AND LIMITATIONS

While other jurisdictions may have different classifications on what is perceived to be utility-scale or large-scale Grid connected solar photovoltaic (PV), one should invoke the relevant rules and codes which govern the specific Grid.

For the Peninsular Malaysia power grid, the Malaysian Grid Code (MGC) sets the regulations and technical requirements that need to be carried out by all parties involved in the planning, management and maintainance of the Grid and distribution systems to ensure the security, safety and reliability of the Grid at all time. According to MGC, any generating plant with the capacity of 50 MW and above shall be bounded by the MGC [5, 6]. For the purpose of this paper, only solar plants that fall under this capacity band will be classified as utility-scale.

In this study, PLEXOS® Integrated Energy Model simulation software by Energy Exemplar was used exclusively in our modelling, therefore the approaches that are presented in this paper are limited to the software's capabilities.

This paper only applies to PV technologies, as that is the only proven solar technology for generating electricity in the Malaysian tropical climate which consists of fast-changing irradiance conditions [7].

UTILITY-SCALE SOLAR PLANT IN MALAYSIA

The pilot project

Malaysia is currently developing its first utility-scale solar PV power plant in the state of Kedah. Announced in April 2014 during the President of the United States of America's visit to Malaysia, this 50 MW solar farm, encompassing a 300-500 acres of land, will be connected at 132kV Transmission voltage. This project is a 60:20:20 joint partnership between the 1 Malaysia Development Bhd (1MDB), national electricity utility Tenaga Nasional Berhad (TNB) and DuSable Capital Management LLC. DuSable, an American private equity firm, will be the technology provider and investment adviser to a private equity fund in which 1MDB will act as a limited partner. 1MDB would reimburse the costs incurred by DuSable arising from the development of the project and associated activities. DuSable, on the other hand, will seek support from the US Government on non-financial matters on the project [8].

TNB, as the Grid owner has signed a 25-year Power Purchase Agreement (PPA) with 1MDB obliging them to buy the power generated with a tariff of between RM0.40 and RM0.46 per kilowatt-hour (kWh). The agreement entails 1MDB to design, construct, own, operate and maintain the solar PV plant [9].

Future capacity allocations

The policy-makers are currently exploring the penetration limit of utility-scale solar for the industry. Possible figures point to the region of 1000 MW capacity target for utility-scale solar by year 2020.

From that portion, 50 MW consists of the successfully negotiated 1MDB plant. The other 450 MW will be awarded through direct negotiations, leaving 500 MW up for the taking. The latest hypothetical capacity allocation of utility-scale solar in Malaysia is illustrated in Figure 1:

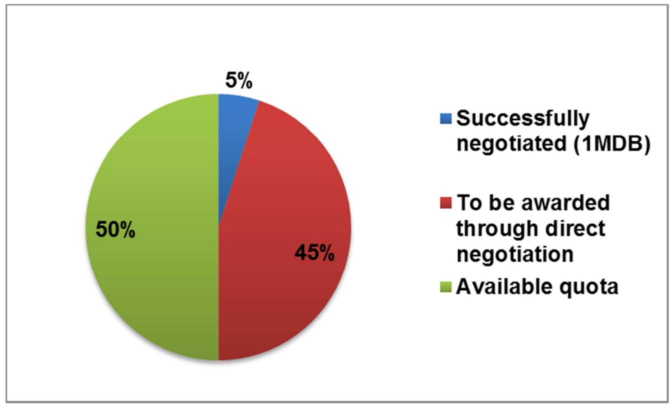

Figure 1 Hypothetical capacity allocation for utility-scale solar in Malaysia

It is still unclear how this 500 MW will be distributed. Being a regulated industry, historically, new generation capacities have been procured by either competitive bidding [10,11] or direct negotiations. Without market forces to reflect the actual energy price, regulated electricity markets such as that of Malaysia requires a policy which emphasises on transparency and non-discriminatory access to the renewable generation sector.

LITERATURE REVIEW

Studies on finding the optimum penetration level of renewable into the grid system have been carried by many others. While all these studies incorporated wind power in their analysis, Malaysia however is not blessed with that type of renewable potential. Nevertheless, these studies offer a lot of insight into the plausible approaches that may be implemented.

Sousa *et. al.* presented a methodology based on constrained multi-objective optimisation and computed the optimal renewable energy mix in the Portugese power system [12].

Halamay *et. al.* [13] presented a methodology for determining a model to predict reserve requirements for areas with high penetrations of wind, solar and ocean wave. This method has shown to be useful towards finding an optimal mix of wind, solar and ocean wave renewable resource.

A recent study by the Energy & Environmental Economics (E3) [14] examines the effects of higher renewable portfolio standards (RPS) in California. The study revealed that in the absence of storage or price-responsive demand, at RPS levels above 33%, the network will suffer from over-generation. Further increasing the state's RPS to 50% by 2030 would result in increase in average retail rates somewhere between 9-23%.

Jo *et. al.* developed a new methodology to assess the optimum capacity of large-scale solar PV in the state of Illinois. By evaluating the solar carve-out portion of the current RPS, they found that the generation from installed PV systems at the current solar carve-out would be fully utilized and none would be wasted [15].

A new study by the International Energy Agency (IEA) concluded that solar PV and wind could generate 30% of a given market's electricity generation without significant economic disruption, depending on the flexibility and the governance of the power market. For any country, the first 5-10% of variable generation pose no technical or economic challenges. However these three conditions must be met: uncontrolled local hot spots must be avoided, the variable generation must be able to support the grid when required and effective forecasting for these type of generation must be practiced. [16].

Studies conducted by the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) and ECOFYS have shown that increasing the installed PV capacity to 70 GW by 2020 shall incur costs of approximately 1.1 billion euros in terms of grid expansion alone [17].

Factorial analysis modelling applied to the Pacific Northwestern power grid of the United States arrived at a specific combination of large-scale solar, wind and solar penetration levels that allows for greater combined penetration rate for the same reserve requirement level [18].

DATA, TOOLS AND METHODOLOGY

For this study, the solar penetration level (SPL) is defined as the maximum AC power output from the solar PV system into the Grid. Since this study focuses on utility-scale solar which is connected at Transmission voltage level, the solar penetration is modelled at the supply side alongside with other conventional generators. Due to data profile limitation, solar penetration is assumed to be connected at one single node.

The solar PV output profile used in this modelling is based on actual site measurement. The sample solar data employed in this study consists of quarter-hourly solar irradiance (G) and output (W) in year 2012. This data was obtained from a test solar system which consists of Siemens/Shell SP75 solar PV panels with a 3.15 kW maximum installed capacity, located in Bangi, Malaysia. Consequently, the sample data was then normalised to the various solar capacity levels modelled in this study. Generation data used is based on the latest approved long-term generation capacity plan for Peninsular Malaysia.

PLEXOS® Integrated Energy Model simulation software was employed to model and simulate output results. Based on recommendations by the Regulator, a Herfindahl-Hirschman (HHI) index of 0.5 [19] was applied and the minimum level of daily gas offtake was set at 600 mmscfd. The price of solar energy was fixed at RM 0.40 cents perKWh based on average cost of intermediate and peak generation unit.

Year 2020 was used as a Base case, considering it is the target year for achieveing the ASEAN RE initiatives of 30% installed RE capacity [20]. The Base case consists of the latest approved generation system in the year 2020 without any solar penetration at grid level. The SPL was then varied from 50 MW up to 2400 MW. The differential cost against the Base case was quantified and the optimum solar penetration level for that year was estimated based on statistical analysis and economic approach.

RESULTS AND DISCUSSION

Impact on Total Generation System Cost

The impact on the total system cost due to utility-scale solar integration in year 2020 was analysed. The total system cost is defined as:

$$\text{Total\_system\_cost} = \text{Total\_Generation\_Cost} + \text{Total\_Fixed\_Cost}$$

where;

$$\text{Total\_Generation\_Cost} = \text{Fuel\_Cost} + \text{Variable\_Operation\_\&\_Maintenance\_Cost(VOM)}$$

and;

$$\text{Total\_Fixed\_Cost} = \text{Capacity\_Payment} + \text{Fixed\_Operation\_and\_Maintenance\_Cost(FOM)}$$

For each SPL, the differential in fixed and operational costs against the Base case were tabulated and shown in Figure 2.

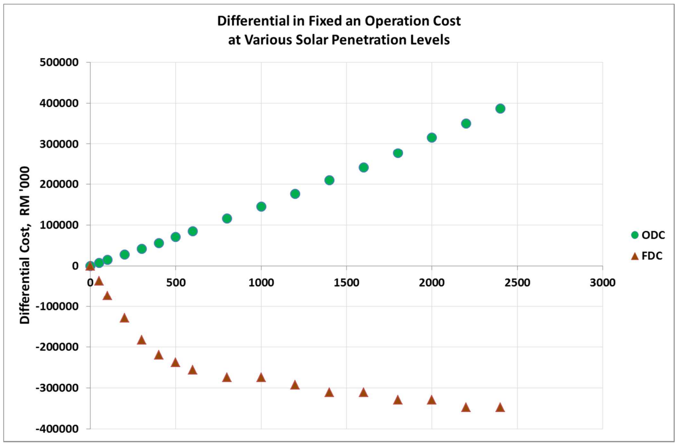

Figure 2 Fixed and Operation Differential Cost at Various Solar Penetration Levels

It can be seen from Figure 2 that, within an SPL of 0 to 2400 MW, solar integration will perpetually incur additional operational cost (ODC), but provide savings in terms of fixed cost (FDC).

Figure 3 is the resulting superimposed graph of ODC and FDC, which gives the total generation system differential cost

(GSDC) against the Base case. It can be observed from Figure 3 that, initially, the rate of change in GSDC follows a negative trend. Beyond the minimum point, the GSDC increases at a positive linear rate i.e. $\frac{d(y2)}{dx} >> \frac{d(y1)}{dx}$. This can be elucidated by imposing two separate linear trendlines representing two visibly distinct regions.

Overall, minimal solar integration into the system will introduce savings against the Base case, due to reductions in capital investments. However, above 2200 MW, this savings are outweighed by the increase in operational cost, leading to additional cost against the Base case. This additional cost is a result of more cheaper units being displaced by solar.

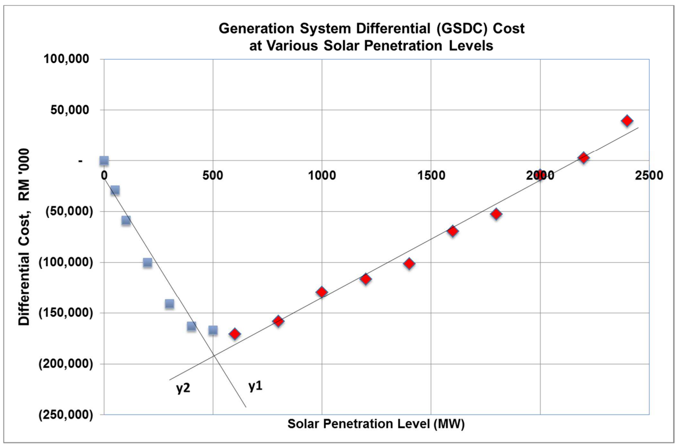

Figure 3 Generation System Differential Cost at Various Solar Penetration Levels

In some systems, the higher cost incurred due to solar integration is the result of additional reserve requirements. Breuer [21] reported a higher share of renewable energy resources requires more reserve capacities. Similarly, Modarresi [22] claimed that the total cost of reserves to cater for high-level of renewable integration will lead to significantly higher additional cost to the overall system. However, based on our analysis, the national grid system will have adequate reserves to cater for this variability. Nevertheless, this reserves is expected to exhaust as the SPL grows in the future.

Considering the fundamental objective of seeking the highest solar penetration target at least cost, the optimal SPL is deduced to be at the local minima of the curve, which is around the 600 MW region. At this point, the system gains the highest savings against the Base case.

However, in light of the national green agenda of promoting RE integration into the energy mix, the SPL may be increased up to 2200 MW, without incurring additional cost to the system. Therefore, the maximum practical SPL limit, may be heuristically deduced to be at 2200 MW.

Impact on Fuel Off-take

The impact of integrating utility-scale solar on the fuel offtake in year 2020 was also evaluated. It was observed that, solar integration will result in slight displacement of both gas and coal generation. However, this impact is expected to be more significant at much higher SPLs. Additionally, as coal-fired plants amount to fifty-percent of the total generation capacity in 2020, operating them in an inefficient manner will not be beneficial to the system.

In other systems, the impact of part-loading of coal generators is more prominent that, coal generators are regularly operated as load-followers, instead of performing their traditional base-load duties. N. Kumar *et. al.* [23] studied the effect of the historical cycling operation of fossil plants in the United States (US) and reported higher cycling mode of operation due to high integration of variable generation into the grid. This has resulted in higher cost of maintenance and operation of these plants. Similar trends were observed for fossil plants in the US, where the National Renewable Energy Lab (NREL) [24] reported that small and larger units of coal-fired generators are expensive load following units. They are designed for base-load operation and will suffer significant damage due to change in operations.

CONCLUSION

The optimum level of utility-scale solar penetration for the Peninsular Malaysia grid in the year 2020 has been evaluated. An economic approach was adopted, whereby the impact of solar penetration to the total generation system cost and fuel offtake were quantified and analysed.

Integrating solar energy into the future energy mix will initially provide savings to the system, up to a certain limit. The optimum solar penetration level, which translates to the highest savings to the system points to the region of around 600 MW. Advancing above this figure, up to 2200 MW, the total system cost is still cheaper compared to the Base case. However, advancing much further from the 2200 MW mark, solar integration will result in additional total system cost against the Base case. Therefore, based on the economic law of diminishing returns, integrating solar above this point will ultimately outweigh the initial benefits gained.

In conclusion, based on this study, the potential range of SPL for the Peninsular Malaysia grid system in the year 2020 appears to fall between 600 to 2200 MW.

Future works

Further areas that could be explored for refining the results and extending the scope of this study are as follows:

- Obtain solar radiation data from various locations
    - This data can be used to model solar generation at multiple nodes/locations

- Apply variable solar price
    - Since GSDC is sensitive to solar energy price, hence there will be different optimum SPL with different solar energy price
- Utilise more recent data sample

ACKNOWLEDGEMENTS

The authors of this paper would like to sincerely express their gratitude and appreciation to Tenaga Nasional Berhad (TNB) for giving consent to publish this paper. The authors would also like to acknowledge Dr. Azrul Mohd Ariffin of Universiti Tenaga Nasional (UNITEN) for providing the solar data sample.

The views expressed in this paper are those of the authors and do not reflect the official policy or position of Tenaga Nasional Berhad, its Management and employers.

REFERENCES

[1] Marcantonini C., Ellerman A.D., The Cost of Abating C02 Emissions by Renewable Energy Incentives in Germany, *10th International Conference in European Energy Market*, Stockholm, Sweden, Pages 1-8, 27-31 May 2013

[2] “The failure of Germany’s green energy policies”. Article from: Institute of Economic Affairs, 1Sept. 2014. [Online]. Available: http://www.iea.org.uk/blog/the-failure-of-germany%E2%80%99s-green-energy-policies

[3] “Ohio's Renewable Portfolio Standard Freeze: How Will It Affect Solar?”. Article from: Renewable Energy World, November 15, 2014. [Online]. Available: http://www.renewableenergyworld.com/rea/blog/post/2014/06/ohio-becomes-the-first-state-to-freeze-its-renewable-portfolio-standard-1

[4] Mohd Zamin N.Z., Zainol Abidin N.Z., and Ibrahim J.B., "Single Buyer – A Step Forward in Malaysian Electricity Supply Industry Reform," in *Proc. IEEE Region 10 Conference (TENCON) Spring 2013*, Sydney, Australia, pp. 396 – 402, 17 – 19 April 2013

[5] Suruhanjaya Tenaga, (2010), The Malaysian Grid Code. Kuala Lumpur, Malaysia. [Online]. Available: http://www.tnb.com.my/tnb/application/uploads/uploaded/the%20malaysian%20grid%20code.pdf

[6] N.Z. Zainol Abidin, Joon B. Ibrahim. “Roles of Single Buyer in Supporting Renewables- The Malaysia's Experience”. Kuala Lumpur, Malaysia. 2014. Unpublished.

[7] R Affandi, M.R. Ab Ghani, C.K. Chin, Jano, Zanariah, “A Review of Concentrating Solar Power (CSP) in Malaysian Environment”, *International Journal of Engineering and Advanced Technology (IJEAT)*, ISSN: 2249-8958, 2013, Volume 3, Issue 2

[8] “1MDB inks mega solar power plant agreement” Article from: The Edge, April 15, 2014 [Online]. Available: http://www.theedgemalaysia.com/business-news/285052-1mdb-inks-mega-solar-power-plant-agreement.html

[9] “1MDB plans giant solar farm”. (2014) Article from: The Star, May 5, 2014. [Online]. Available: http://www.thestar.com.my/Business/Business-News/2014/05/05/1MDB-plans-giant-solar-farm-It-is-believed-to-have-formed-a-joint-venture-with-TNB-and-a-US-firm-fo/

[10] Mohd Sopian A, Ibrahim J.B., and Zainol Abidin N.Z., "International Competitive Bidding for New Generation Capacity: The Malaysia’s Experience," in *Proc. Scientific Cooperations International Conference in Electrical and Electronic Engineering*, Istanbul, pp. 195 – 201, 5 – 7 September 2013

[11] Suruhanjaya Tenaga. “Competitive Bidding for Combined Cycle Power Plant”. [Online]. Available: http://www.st.gov.my/index.php/industry/competitive-bidding-for-combined-cycle-power-plant.html

[12] Sousa J, Martins A, Optimal Renewable Generation Mix of Hydro, Wind and Photovoltaic for Integration into the Portugese Power System, *10th International Conference on European Energy Market*, Stockholm, Sweden, Pages 1-6, 27-31 May 2013

[13] Halamay D.A., Brekken T.K.A., Simmons A, McArthur S, Reserve Requirement Impacts of Large-Scale Integration of Wind, Solar, and Ocean Wave Power Generation. *IEEE Transactions on Sustainable Energy*, Volume 2, 2011, Issue 3, Pages 321-328

[14] Energy Environmental Economics, Investigating a Higher Renewables Portfolio Standard in California, January 2014 [Online]. Available: https://ethree.com/documents/E3_Final_RPS_Report_2014_01_06_with_appendices.pdf

[15] Jo J.H., Loomis D.G., Aldeman M.R., Optimum Penetration of utility-scale grid-connected solar photovoltaic systems in Illinois, Renewable Energy 60(2013) 20-26

[16] International Energy Agency.The Power of Transformation-Wind, Sun and the Economics of Flexible Power Systems, ISBN 978-92-64-20802-5. 2014

[17] “Recent Facts about Photovoltaics in Germany”, Fraunhofer ISE, April 10, 2014. [Online]. Available: http://www.ise.fraunhofer.de/en/publications/veroeffentlichungen-pdf-dateien-en/studien-und-konzeptpapiere/recent-facts-about-photovoltaics-in-germany.pdf

[18] Halamay D.A., Brekken T.K.A., Factorial Analysis for Modeling Large-Scale Grid Integration of Renewable Energy Sources. *Proceedings of IEEE PES Trondheim PowerTech*, Trondheim, Norway, Pages 1-9, 19-23 June 2011.

[19] MyPower Corporation. “Determining the Fuel Mix and Security Policy for the Power Sector”. Kuala Lumpur, Malaysia. 3 April 2014. Unpublished.

[20] Sustainable Energy Development Authority Malaysia. “Proposal on Implementation of Utility Scale Solar (USS)”. Presented at USS Workshop, Bangi, Malaysia. 17 February 2015. Unpublished.

[21] Breuer C, Engelhardt C, Moser A, Expectation-based Reserve Capacity Dimensioning in Power Systems with an Increasing Intermittent Feed-in,“ in Proceedings of the Conference on European Energy Markets, Stockholm/Sweden, 27.05.-31.05.2013

[22] Modarresi M S, Xie L, An Operating Reserve Risk Map for Quantifiable Reliability Performances in Renewable Power Systems. IEEE PES General Meeting | Conference & Exposition, National Harbour, Pages 1-5, 27-31 July 2014.

[23] Kumar N, Paterson S, Coleman K, Lee C, Agan D, Lefton S, Power Plant Cycling Measure- Evaluating Historical Cycling to Model Future Grid Operations, *Power and Energy Society General Meeting (PES)*, 2013 IEEE pages 1 – 5 Vancouver, BC , 21-25 July 2013

[24] Kumar N, Besuner P, Lefton S, Agan D, Hilleman D, Power Plant Cycling Costs, National Renewable Energy Laboratory, April 2012 http://www.nrel.gov/docs/fy12osti/55433.pdf