Determining the Required Reserve Margin to Maintain a Reliable Electricity Supply in Singapore

Measure of Reliability

Over the past decade, Singapore adopted a generation capacity reliability standard metric of Loss of Load Probability (LOLP) of 3 days per year. LOLP of 3 days per year represented three instances of lost loads in a year, when the available generation capacity was insufficient to serve the daily peak demand, as a result of scheduled maintenances, unscheduled repairs and forced outages of generating unit(s).

As more intermittent generation sources and other new technologies will be connected to the power system, EMA engaged a Consultant, in 2018 to review the requirements to determine if the reliability standard metric of LOLP of 3 days/year was still adequate to ensure the reliability and security of the power system in Singapore.

The Consultant had recommended for Singapore to adopt the reliability metric Loss of Load Hours (LOLH), which represents the expected number of hours per year when available generating capacity is insufficient to serve the hourly demand across all hours of the year rather than just daily peak demand, because LOLH is a better indicator to measure the hourly impact of intermittent generation sources.

The Consultant also recommended Singapore to set a reliability standard that factors the trade-off between the value placed by consumers on uninterrupted electricity supply and the cost of adding new capacity to deliver increased reliability. The key consideration was to minimise the total system cost which comprises the costs of required generation capacity and costs of unserved energy. A higher amount (and cost) of generation capacity is required to lower LOLH. However as LOLH decreases, the cost of unserved energy is correspondingly reduced. A chart on diminishing returns of LOLH reduction for every one percent increment in reserve margin is shown in Figure 1.

Derivation of Required Reserve Margin (RRM)

A required reserve margin of 27% was derived from 3-hours of loss of load hours (LOLH) per year. This represents 3 hours of lost loads in a year, when the available generation is insufficient to serve the demand, as a result of scheduled maintenances, unscheduled/ad hoc repairs and forced outages of generating unit(s). The derivation was performed through Monte Carlo simulation runs which took into account peak system demand forecast, planned and unplanned outage rates of generating units including intermittent solar PV generation. In the simulations, the planned outage rates were based on the scheduled maintenances submitted by the generation companies whereas the unplanned outage rates were based on the generating units' historical average. The installed solar PV capacity was projected to reach 2GWp by 2030 and its intermittent generation was estimated from the historical minute-to-minute output fluctuations. In addition, the peak electricity demand was forecasted to reach around 9,300MW by 2030.

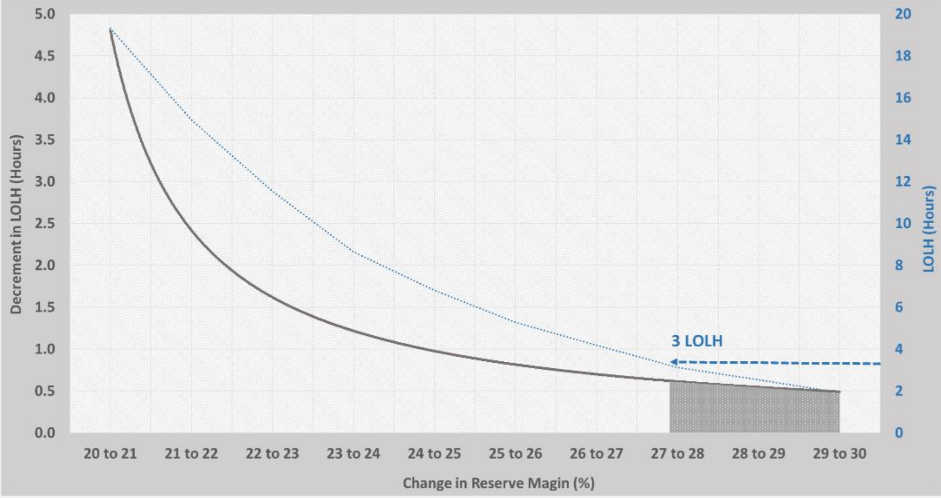


Figure 1: Diminishing returns of LOLH reduction for incremental reserve margin (%)

A schematic diagram of the simulation process is presented in Figure 2 below and an illustration of how LOLH is computed is attached in Annex 1 for reference.

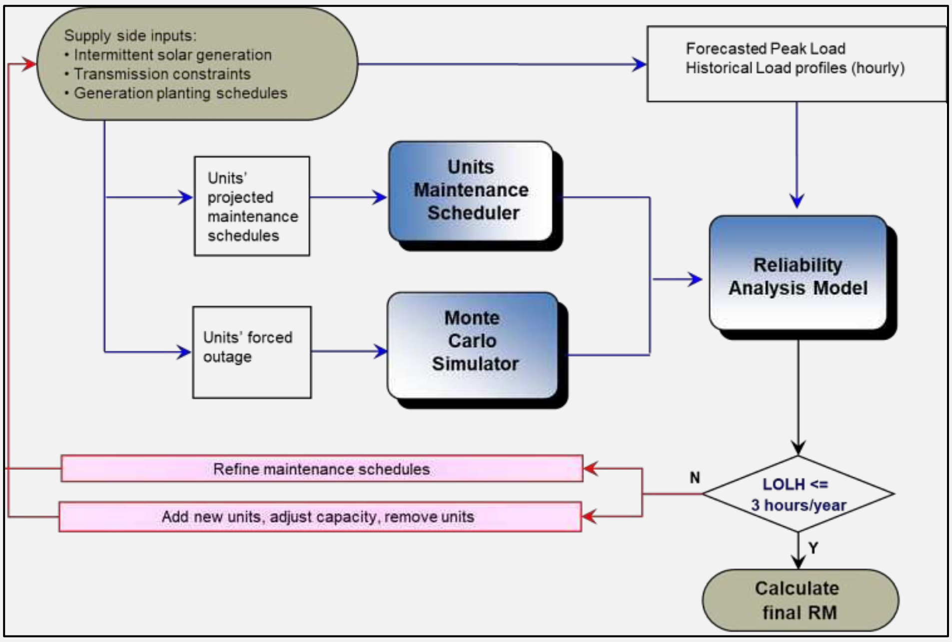


Figure 2: Flowchart to calculate Reserve Margin

In comparison to other countries of similar living standards as Singapore, United States of America, Great Britain and Ireland have reliability standard metrics of 2.4-hours, 3-hours and 8-hours LOLH respectively.

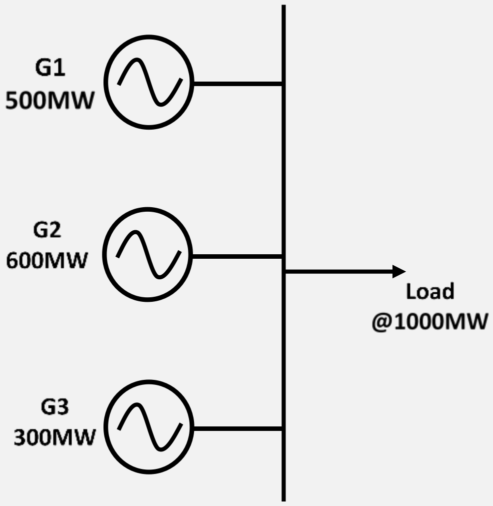
How RRM changes with system demand and power plant sizes

As system demand increases, there will generally be more generating units in the power system to serve the demand. Correspondingly, there will also be more generating units to stagger scheduled maintenance and provide back-up during forced outages, and the required reserve margin may be lowered. Hence, the derived RRM is lower than the one based on 3-days of LOLP, i.e. 30%, despite accounting for all hours (instead of peak hour) of the day, because the system demand has increased over the past decade. On the other hand, if the installed capacity of a power plant increases, e.g. from 400MW to 600MW, a larger generation capacity may be unavailable during planned and unplanned outages. As such, a higher reserve margin may be required to meet the same reliability standard.

Annex 1 – Illustration of how LOLH is calculated

To illustrate the LOLH calculation, an example which assumes that there are only three generators in the system supplying a demand of 1000MW in a period, is presented below. To calculate the LOLH, we need to determine possible events and likelihood of occurrences of these events.

The LOLH is the sum of probabilities of all events when load is not fully supplied. The number of events equates to 2^N where N is the number of generators in the power system. Hence in this case, the LOLH can be computed as follows.



Generator	Capacity (MW)	Availability (%)
1	**500**	**95**
2	**600**	**85**
3	**300**	**98**

Outages Event	Probability of Occurrence	Amount Load Loss (MW)
None out	(0.95)*(0.85)*(0.98) = 0.79135	0
G1 out	(0.05)*(0.85)*(0.98) = **0.04165**	100
G2 out	(0.95)*(0.15)*(0.98) = **0.13965**	200
G3 out	(0.95)*(0.85)*(0.02) = 0.01615	0
G1 & G2 out	(0.05)*(0.15)*(0.98) = **0.00735**	700
G1 & G3 out	(0.05)*(0.85)*(0.02) = **0.00085**	400
G2 & G3 out	(0.95)*(0.15)*(0.02) = **0.00285**	500
All out	(0.05)*(0.15)*(0.02) = **0.00015**	1000

In this example, LOLH (hours) = 0.04165 + 0.13965 + 0.00735 + 0.00085 + 0.00285 + 0.00015 = 0.1925.

Annex: Write-up on Peak Demand Forecast Methodology and Forecast Accuracy

The peak demand forecast is derived from total electricity demand forecast, taking into account the historical (i) distribution and transmission losses, and (ii) overall system load factor. Total electricity demand, which is a summation of residential and non-residential electricity demand, is forecasted using econometric modelling to determine the relationships between electricity demand and its economic (i.e. GDP)[1], demographic (i.e. population)[1] and weather (i.e. temperature)[2] drivers (see Equations 1 and 2 below).

$$(\text{Residential Electricity Demand})_t = \alpha_0 + \alpha_1(\text{Population})_t + \alpha_2(\text{Temperature})_t \quad \text{Eq [1]}$$

$$(\text{Non-Residential Electricity Demand})_t = \beta_0 + \beta_1(\text{GDP})_t \quad \text{Eq [2]}$$

Where α_0, α_1, α_2, β_0 and β_1 are coefficients to be estimated through linear regression with yearly data from 2004 to the latest available year.

EMA regularly obtains the internal forecasts of the economic, demographic and weather input drivers from the Ministry of Trade and Industry (MTI), the Singapore Department of Statistics (DOS) and the National Environment Agency (NEA) respectively.

EMA's 1-year ahead peak demand forecasts have a historical average accuracy of 98%, while the 4-year ahead peak demand forecasts have a historical average accuracy of 91% (refer to Table 1 for more details). To enhance the accuracy of the forecasts, EMA reviews the forecasts annually with updated input drivers from the respective agencies.

Table 1: Peak Demand Forecast Accuracy

Year-ahead	Historical Average Accuracy[3]
1-year ahead	98%
2-year ahead	96%
3-year ahead	94%
4-year ahead	91%

In recent years, new and high growth sectors such as Data Centres (DCs) have emerged in Singapore. Such sectors typically ramp up quickly and may not be sufficiently captured through the above-mentioned macro-economic indicators. To account for these new and high growth sectors, projections of these sectors are exogenously added[4] onto the overall demand forecasted using the electricity demand forecast model above.

The peak electricity demand of DCs in Singapore in 2019 was around 330MW, representing about 4.5% of peak system demand in 2019. A survey, covering most large DC players, was conducted last year to understand the projected power requirements of DCs in Singapore. Based on the survey, peak electricity demand of DCs could range from 1,000MW to 1,500MW by 2025. This could shift the 2025 peak electricity demand in SEMO 2019 from between 8,150MW and 8,500MW to between 8,900MW and 9,700MW. EMA will continue to monitor the projected growth of DCs in Singapore and provide timely updates to the industry.

[1] Historical data on GDP and population could be accessed at Singtstat Table Builder at the following link: https://www.tablebuilder.singstat.gov.sg/publicfacing/mainMenu.action
[2] Historical data on temperature could be accessed at Data.Gov at the following link: https://data.gov.sg/dataset/surface-air-temperature-mean-daily-minimum

[3] Based on comparing forecasts to actual peak demand values from 2011 to 2019.
[4] Appropriate adjustments to the model will be made to avoid any double counting of these sectors' demand when adding them to the overall demand forecasted.