Assessment of Ramp-Capability and Reserve Margin Requirement for the State of Tamil Nadu with High RE-Penetration for Year 2022

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Abstract— **The possible challenges of high Renewable Energy (RE)-integration arise when the online generators are short of ramping capability and offline generators need time to come online to meet the ramping requirements. To improve flexibility and security of power system for RE accommodation, additional reserve margin may be required. This paper analyzes the net load variations and developing ancillary service requirements to support renewable expansion, the determination of appropriate constraints that reflect the additional variability and short-term uncertainty introduced by RE generation through statistical analysis.**

By 2022, the MNRE targets total 160 GW variable RE (vRE i.e. wind and solar) installation in India with highest RE targets for the state of Tamil Nadu, 8,884 MW Solar and 11,900 MW Wind. To put this in context, the projected Peak demand in 2022 for Tamil Nadu is around 21.5 GW while peak demand for the Southern Region is around 66.7 GW (as per 19th Electric Power Survey of India), thereby indicating that in absolute terms the total RE installed capacity in Tamil Nadu is ~94.14% of the state's peak demand and 31.15% of the Region peak demand. Analyzing such large RE installation in a state is crucial for the dispatchers to understand and quantify the impact on the thermal power plant performance and maintaining the system stability.

High-resolution load and vRE production data for a chronological period are the primary inputs to this analysis. For each 15-minute interval, the change in net load is calculated to determine the variability in vRE generation within the hour. Then mathematical and statistical techniques was applied to characterize and quantify this variability in the case where reserve requirements are determined prior to the operating hour. These statistical characteristics are required to develop reserve requirements. The process starts with the determination of 15-minute variability in vRE generation (Delta), followed by utilizing this variability to determine the standard deviation limits within which the vRE generation is likely to deviate from the forecasted values (Sigma Delta). Based on experiences gained from previous instances, it was empirically estimated that about 2.5σ may be sufficient to provide reserves to cover most of the intra-hour variations in Wind and Solar. Some values of deviation between consecutive time-blocks may be exceptionally high, which is dependent on the accuracy of forecast, and as such these values are considered as outliers and may be excluded from actual calculations.

Developing operational reserve requirements from variability metrics is an evolving science. This paper evaluates the reserve requirements that use current hour values of load and wind and solar generation along with forecasts of those quantities for the next time slot as inputs. Analyzing the standard deviation will help in determining the reserve requirement to cover most of the inter-hour variability due to vRE generation.

Keywords- Statistical Analysis, Renewable Energy variability, Renewable Energy Integration, Net Load Analysis, Ramp Capability, Reserve Margin

I. INTRODUCTION

Tamil Nadu is one of the largest consumers of electricity in India. Together with domestic consumers, high industrial and commercial activity the per capita electricity consumption in the state was 1,280 kWh in financial year (FY) 2016, making it the third largest consumer (~9% of total energy consumption) in India. Tamil Nadu is a highly urbanized state with about 48.3% of the state's population residing in urban areas.

The state has achieved a high rate of electrification compared to the national average and was able to meet the peak demand of 14,533 MW and an energy requirement of 100,319 MU's in FY2016. The demand in FY2022 is projected to be 21,471 MW of peak and 144,145 MU's of energy requirements as per the 19th Electric Power Survey (EPS). The domestic and industrial sectors are major drivers for electric demand. The industrial sector comprised 35% of the electric consumption in FY2016 while being 2% of the total consumers. Similar trends are projected for FY2022 as per the 19th EPS. Utilities in Tamil Nadu encourage utilization of open access channels of procuring electricity for industrial consumers, many of whom procured power through open access or set up their own captive generating stations.

Thermal power plants form the largest share of the generation mix providing the bulk of electric power with an installed capacity of 16,339 MW as of June 2019 as shown in Figure 1. Thermal capacity includes allocation from central generating stations. By 2019 2,509 MW thermal capacity will be coming from central sector plants. In addition to the central sector capacity allocation, the utility in Tamil Nadu is undertaking construction of thermal power plants totaling about 4,300 MW by end of FY2021.

Renewable capacity is the second largest installed capacity in the state with 13,117 MW as of June 2019. In FY2016 the state had a capacity of 7,642 MW of wind capacity and 1,155 MW of solar capacity. Their contribution to the Renewable

Energy (RE) capacity in 2019 is set to increase with an addition of 2,000MW of wind and 3,000MW of solar capacity.

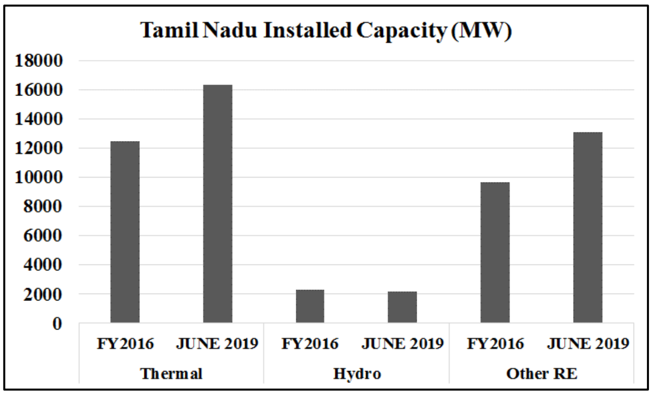

Figure 1: Tamil Nadu Installed Capacity

The Ministry of New and Renewable Energy (MNRE) has targeted a total capacity of renewable capacity in Tamil Nadu by 2022 of 20,784 MW (8,884 MW solar and 11,900 MW of wind). In absolute terms the RE installed capacity in Tamil Nadu is ~94.14% of the state's peak demand in 2022. [1]-[4]

With such large contribution of vRE sources to the state grid, dispatchers would need to assess the impact of vRE generation on thermal capacity as well as to determine the reserve margin requirements to maintain the reliability of the system. Prediction of vRE generation would help to estimate the performance of the system and make dispatch decisions for thermal generation more reliable.

II. Statistical Analysis of Wind and Solar Generation Profiles

The statistical analysis is evaluated in this paper to assess the ramping requirement of the state of Tamil Nadu (TN) due to highest RE-penetration in India by 2022. High resolution sub-hourly data (15 mins/ total 35,040 samples) for RE-profile and Load-Profile were captured which enhanced the accuracy of statistical analysis. The day ahead sub-hourly wind and solar profiles for 2022 were obtained from an external service provider. Sub-hourly load profile of TN was calculated from the load data available in Southern Regional Load Dispatch Centre (SRLDC) website for 2015 and extrapolated based on the peak demand of TN for the year 2022. Ultimately, Net-Load profile was calculated by subtracting Sub-hourly vRE profile from Sub-hourly Load.

Surface plots are the three-dimensional diagrams of a set of data points that are useful for investigating the desirable response values and operating conditions. In this analysis, vRE and Net-Load data points are plotted in Z axis as height and month & hours are plotted in X-Y plane which are shown in Figure. 2 & 3.

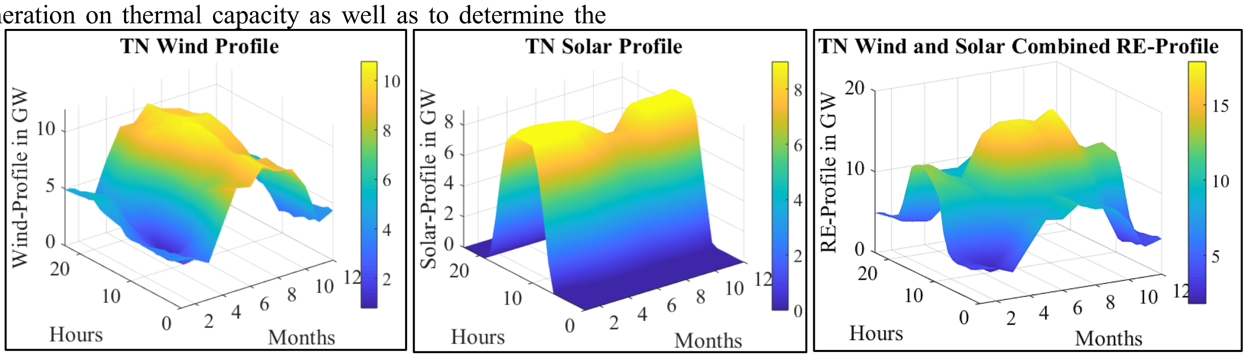

Figure 2: Surface Plots of Wind, Solar and Combined Wind & Solar

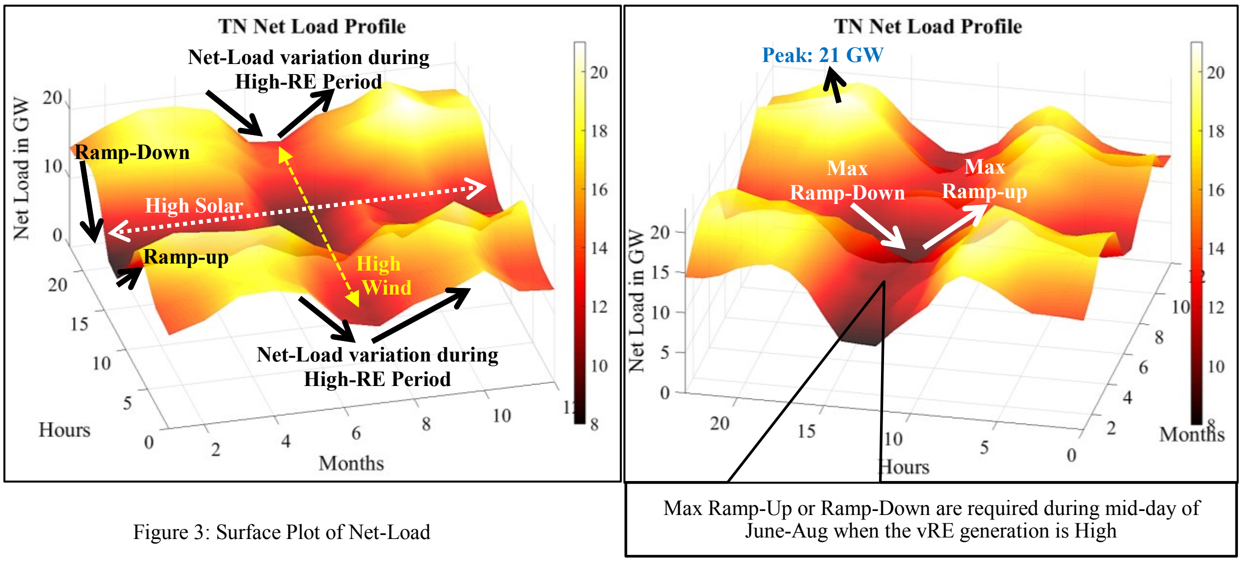

Figure 3: Surface Plot of Net-Load

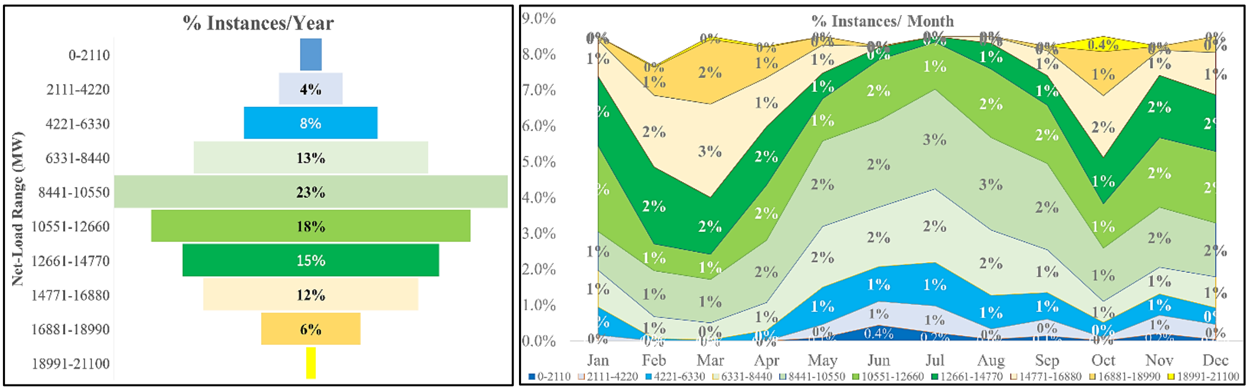

Figure 4: Net-Load Range and yearly/monthly % instances or Ramping requirements

Month-wise maximum hourly generation for wind, solar and combined wind and solar profile are depicted in Figure. 2. Wind power generation peaks at ~10,763 MW during June-August, while the minimum is ~800 MW for the given time block around mid-day in January-May.

Solar power generation peaks at ~8,000 MW around mid-day during the period from January–May and October-December. Reduced peak is visible in June-September for wet-season.

Combined wind and solar peak at 17,877 MW around the mid-day of June-August when both wind and solar are available. Wind and solar generation mostly complement each other, wind would be available during the night when solar is not present and solar is at its peak during the day when wind generation is low. Net-Load is basically captured as total load less vRE generation. The maximum dip of Net-Load is seen during June-August months (high vRE period) as shown in Figure. 3. Thermal units need to be Ramp-Up or Ramp-Down to compensate the variability of Net-Load. Gas based plants such as the combined cycle units are important during the initial period of ramp up requirement in view of the longer start up time for the coal plants.

Two important aspects of this analysis are:

I. Net-Load variation/DeltaP/Ramping requirement: Net-Load Variation is calculated by subtracting the consecutive samples of Net-Load to evaluate the Ramp-Up and Ramp-Down requirements in sub-hourly basis.

II. Net-Load Range: Sub-hourly Net-load capacity (Difference between Sub-hourly Load and vRE profile) is divided into equal sized blocks (the number of blocks is dictated by the granularity required in the analysis) in the range from 0 MW to maximum Net-Load output. In each range the (percentage) % instances/year has been counted to assess the statistical characteristics of different range of Net-Load variation. The yearly and monthly distribution of % instances for each Net-Load range is shown in Figure. 4. Further, Net-Load ranges are categorized as:

- ✓ Low Net-Load Range (0-7 GW) → Blue: Ramping requirements are mainly appeared in the peak vRE-period (May-September) with total 13% instances/year.
- ✓ High Net-Load Range (7- 14 GW) → Green: Ramping requirements are observed throughout the year and maximum no. of %instances/year (69%) occur with this range. Maximum %instances/year for Net-Load Range (8,441-10,550 MW) is 23% which occurs during the high vRE period (May to September).
- ✓ Highest Net-Load Range (14-21.1 GW) → Yellow: Ramping requirements are mainly appeared in the low vRE-penetrated period (January-April, October-December) with total 18% instances/year.

Average hourly Net-Load variation for each month with low range (0-7 GW) of Net-Load variation are as depicted in Figure. 5. In this case the average Ramp-Up and Ramp-Down is concentrated mainly during the months June-Aug with high RE-Penetration situation. % instances in this case is low as compared to high Net-Load range. Figure. 6 shows the average hourly Net-Load variation (Ramp-Up and Ramp-Down) for each month with high range (7-14 GW) of Net-Load variation where the average hourly Net-Load variation (ramping requirement) is uniformly distributed throughout the year. Average hourly Net-Load variation (The Ramp-Up and Ramp-Down) for each month with highest range (14-21.1 GW) of Net-Load variation is visualized in the Figure. 7. The (percentage) % instances are found to be very low and largely to cater the load demand during low vRE periods.

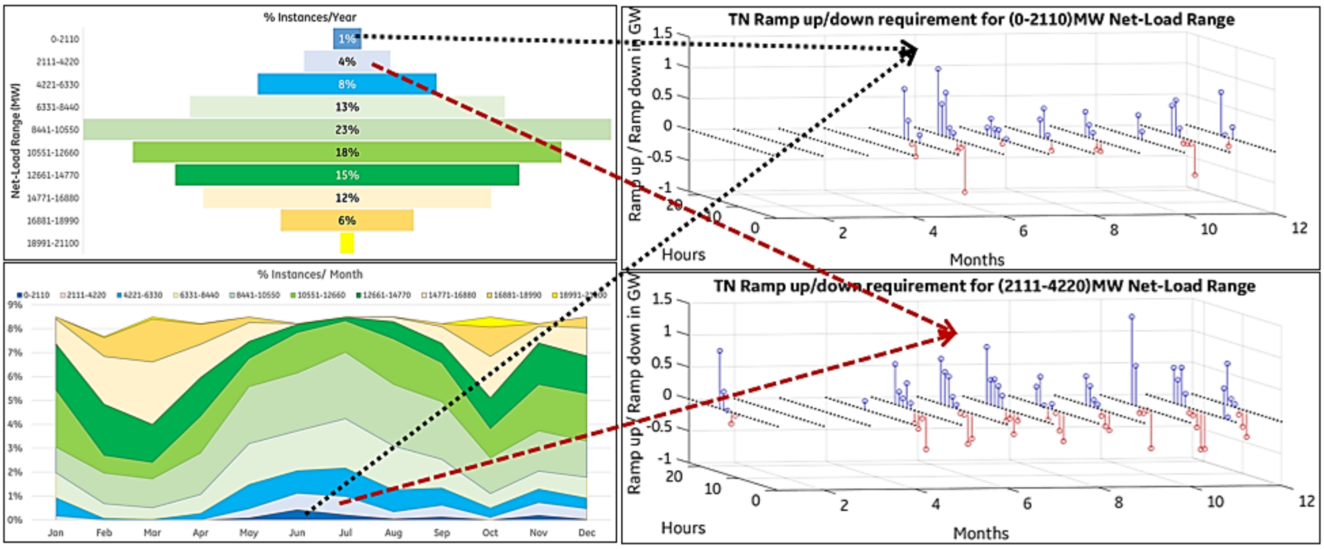

Figure 5: Ramping Requirement with Low Net-Load Range (0-7 GW)

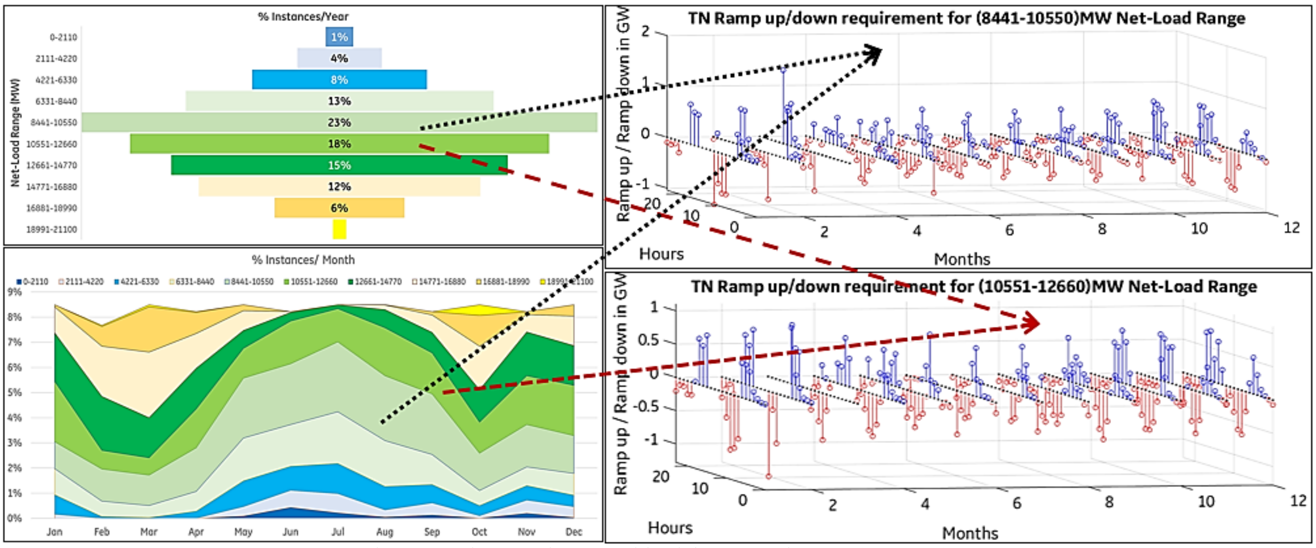

Fig 6: Ramping Requirement with High Net-Load Range (7-14 GW)

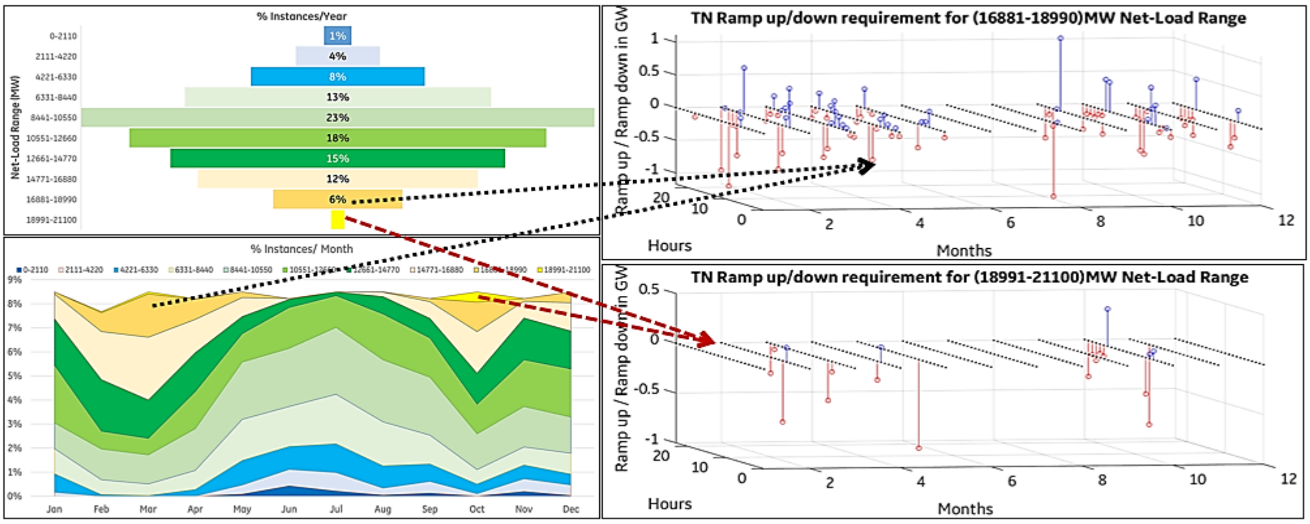

Figure 7: Ramping Requirement with Highest Net-Load Range (14-21 GW)

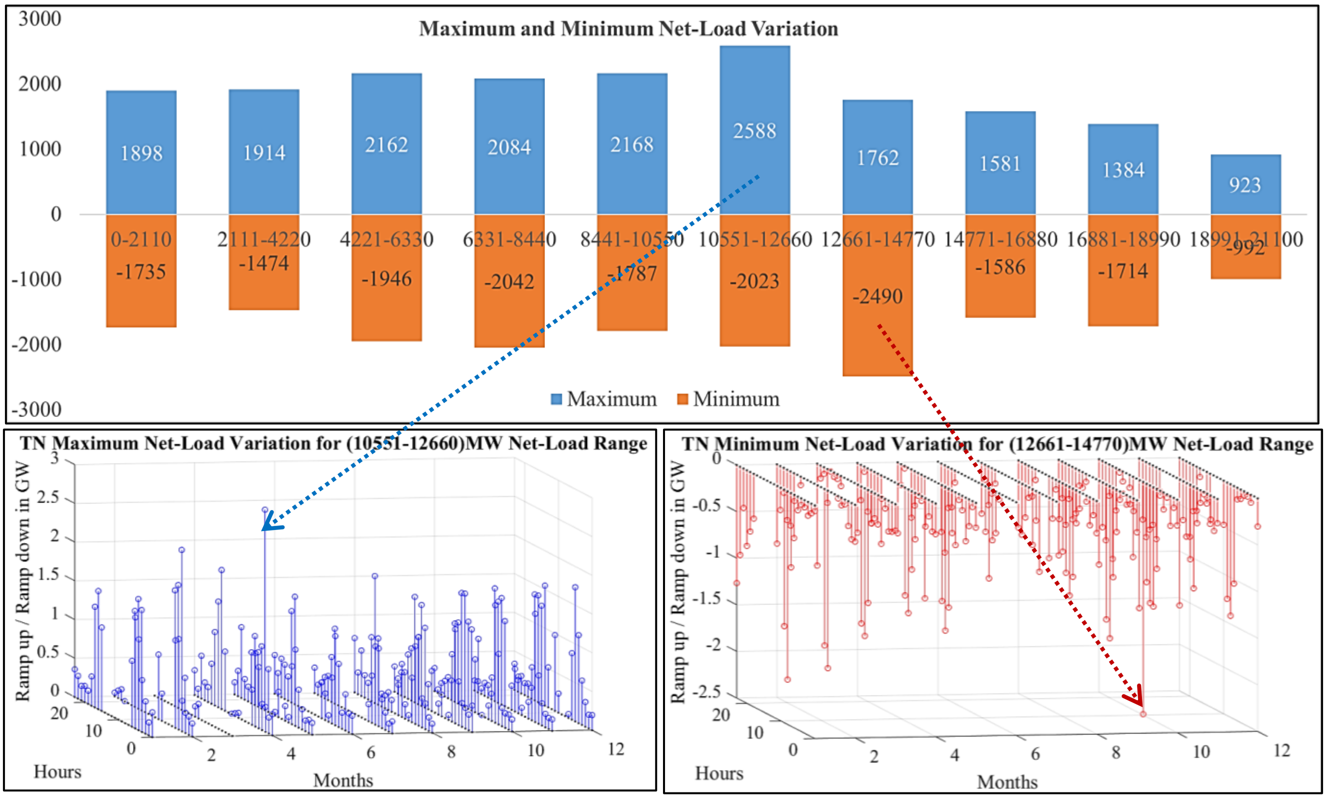

Figure 8: Minimum and Maximum Net-Load Variation

Figure 8 captures the maximum and minimum Net-Load variation.

- The net load variation range (max and min) on a MW/15 min basis (ramping capability) is: +2,588 MW (10,551-12,660 MW range) to -2,490 MW (12,661-14,720 MW range).
- The maximum Ramp Up or maximum Net-Load variation per hour is ~ 2.6 GW.
- The maximum Ramp Down or minimum Net-Load variation per hour is ~ 2.5 GW.
- Maximum Ramp-Up and Ramp-Down is occurring with high Net-Load range.
- Capability to meet this variability is dependent on the extent of flexible generation available and the support from neighboring states.

III. Reserve Requirement Assessment based on vRE generation

High resolution vRE profile (15min/35,040 samples) were utilized to determine the reserve requirements in 2022 for Tamil Nadu. Reserve requirements on the account of vRE variability that needs to be maintained by the grid operator is calculated here based on simple statistical methods. The outputs of these analysis would yield an indicative value of the reserves that need to be maintained for the state in 2022 on account of the total vRE target being achieved. The analysis is dependent on the accuracy of the forecasted vRE profile, the performance parameters of the wind and solar power projects such as their expected capacity factor would influence the reserve calculations.

Statistical analysis in the sub-hourly data set of vRE generation (wind and solar) for the total installed capacity of 20,784 MW (wind and solar) was performed beginning with dividing the dataset into equal sized dispatch blocks (based on the peak generation) of combined vRE profile. The variations between consecutive dispatch intervals are then categorized into respective blocks. Figure 9 shows the scatter plot of the combined vRE variation which shows the highest variation to be in the range of approximately $\pm$2,000 MW barring some outliers. The standard deviation in each block is calculated to derive a trend line curve.

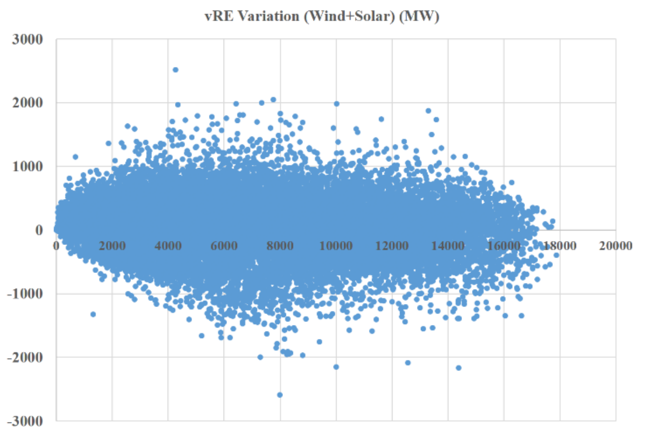

Figure 9: vRE variation (Wind + Solar)

The standard deviation of the delta (sigma "σ" delta) for each of the blocks are calculated and is shown in Figure 10. The standard deviation in each block indicates that most of the variability occurs during peak generation of vRE sources as seen in the higher range blocks. Variation in generation for wind or solar is lower during periods when the generation is expected to be at its peak or at its lowest. Such as forecast of solar generation would be predictable or more accurate for periods like night-time or during mid-day in summer months. For wind generation forecasts, the variations would be less during high wind periods. When analyzing the combined generation of wind and solar, the variations would not be as predictable as when they were considered separately. This is due to the difference in quantum of wind and solar power in the system and the difference in the time of power generation.

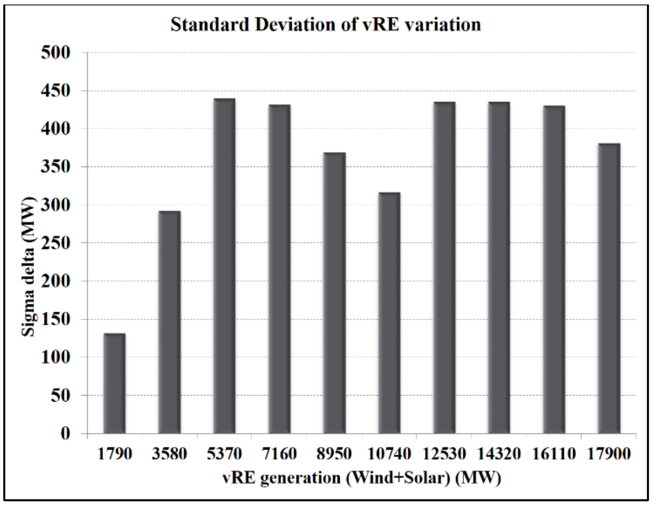

Figure 10: Standard Deviation of vRE variation

Based on the sigma delta (σ) blocks a curve fit is made using the trendline curve function in MS-EXCEL, to determine the equation which can be used to calculate the reserve requirements based on the vRE generation profile. The trend line is shown in Figure 11.

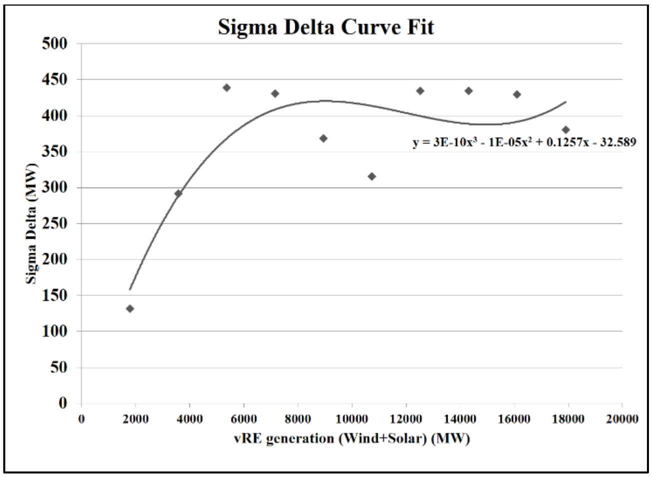

Figure 11: Sigma Delta Curve Fit

equation of the curve fit is

$$y=3e^{-10}x^{3}-1\ e^{-10}x^{2}+0.1257x-32.589$$

The standard deviation (sigma delta) trendline equation is used to determine the variability for each dispatch interval. The Central Electricity Regulatory Commission (CERC) released a report on spinning reserve requirements [5] in 2015. In the report it is mentioned that a 2σ to a 4σ could cover 95 to 99% of the variability [5]. Based on the data set utilized for this analysis a 2.5σ (sigma delta) covers more than 98% of the variations which means that the variation being greater than 2.5σ is less likely. At 1σ the maximum reserve requirement for the projected vRE generation is approximately 720 MW, and to cover the majority of the vRE variation, a reserve requirement of approximately 1,800 MW (2.5σ) would be required.

The carpet plot depicting the reserve requirement for the state of Tamil Nadu in 2022 based on the combined vRE (Wind + Solar) is shown in Figure 12. The carpet plot is obtained by taking the average value of the reserve requirement (based on the combined wind and solar generation) of each hour of the day for each month. The reserve requirements are highest during peak hours in June-August period which coincides with high variations in wind and solar generation.

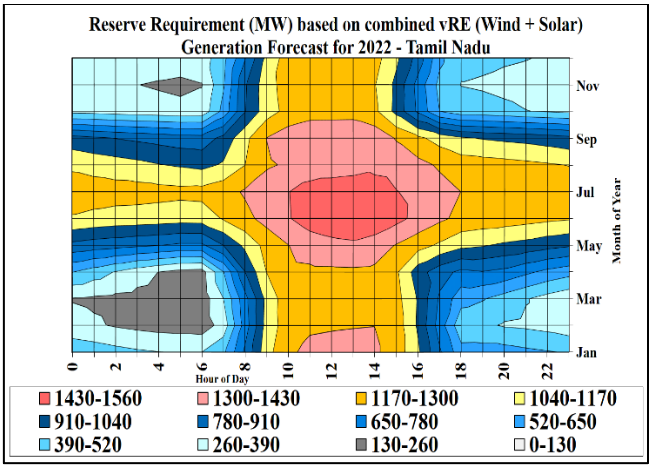

Figure 12: Reserve Requirement due to combined vRE generation forecast for 2022-Tamil Nadu

With the addition of significant vRE to the capacity mix and their increased contribution to the generation mix, the system stability and reliability needs to be maintained. Estimating a reserve requirement would provide the necessary estimates the grid operator could utilize to help maintain system stability.

IV. Key Observations

- In Tamil-Nadu wind installation will be high as compared to solar by 2022.
- Ramp Up/Down or Net-Load variability is maximum ~ 23% instances/year with high Net-Load range during high RE-penetration.
- Low Net-Load range and highest Net-Load range are mainly during high RE and low RE time horizon respectively.
- The maximum Ramp-Up (maximum Net-Load variation) and Ramp-Down requirement (minimum Net-Load variation) per hour is ~2.6 GW/hour and ~2.5 GW/hour respectively with High Net-Load range.
- Based on the vRE generation profile the estimated variation of 2.5σ would cover majority of the vRE (Wind +Solar) variation for the state.
- Highest variation is observed in June to August period as it coincides with high variations in wind and solar generation.

Acknowledgment

The process and steps elaborated in this paper are presented at a high-level for the assessment of the impact of integrating large amount of variable RE in the state of Tamil Nadu. The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the institutional views of General Electric Company. The Authors or General Electric Company shall not be liable to any claims of

whatsoever nature arising as a result following the views expressed in this paper.

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Dr. Ankita Samui is a Senior Engineer in the Power Economics team of GE Energy Consulting, Bengaluru, Karnataka, India. Dr. Samui holds a B.Tech, ME and PhD degree from WBUT, BIT Mesra and IIT Bhubaneswar, respectively. Dr. Samui's research area includes Islanding detection in distributed generation (PhD), Distribution system planning with reliable feeder routing (ME) and DFIG Based Wind Turbine Protection and Optimal Power Flow (GE GRC).

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