Renewable Resource Production Metrics and Measures

Wyoming Infrastructure Authority and Power System Resources

By: James Detmers, PE---Final Report July, 2015

Executive Summary

Given the upcoming changes that are transforming the electric power system with ever increasing renewable supplies which have variable production supply curves, grid engineers face major challenges in maintaining power quality while achieving both the service reliability to customers and the grid reliability of the power system. The new variable renewable supply characteristics being added to the network effect grid performance parameters in differing ways depending on location of grid interconnection and type of resource. It is becoming increasingly evident that additional performance attribute parameters and engineering tools are needed to inform planning and operational decisions. This ongoing analysis and study establishes a new set of metrics for quantifying the critical parameters effecting power quality and reliability for supply variations of a renewable portfolio, as well as the supply variations for a Balancing Authority with renewable production. These new metrics will be useful to system operators planning daily operations, merchant buyers of renewables to minimize costs of replacement energy, and engineers evaluating proposed renewable projects that for overall system technical and economic viability prior to contracts being authorized for project construction.

The power system is a complex machine that operates under numerous standards including supply and demand balancing that must be maintained within very tight tolerances[1], in order to maintain system frequency and voltage. These standards or reliability requirements are mandatory under U.S. Federal Law and are defined and set by the North American Electric Reliability Corporation, NERC. As production metrics are introduced to the industry they will further mathematically define the renewable supply variations, resulting in mitigating supply requirements. Limits to the supply variations can then be specified, which will be needed to maintain and restore power quality and reliability of the grid and minimize the integration costs for the new generating sources.

This work initially started with the University of Wyoming (UW) which determined significant benefits for integrating geographically diverse renewable sources. These benefits can be achieved by combining geographically diverse renewable sources such as Wyoming wind with its much higher capacity factors with California's renewable supplies. Not only does Wyoming wind contribute to greater amounts of power for a given amount of nameplate capacity, it also peaks in the afternoon and evening which is coincident with the load profile on the California Power System.

[1] Balancing tolerances refer to the NERC Bal standards such as CPS 2 which require a Balancing Authority to maintain supply and demand within approximately +/- 100 MW on a system supplying over 30,000 MW or more in the case of the CAISO, every 10 minutes 7X24.

This report cites findings of the UW studies presented by Dr. Jonathan Naughton, Professor of Mechanical Engineering at UW. Referencing Dr. Naughton's work will help explain in detail, the calculations and data sources mentioned in this report.

Establishing clear and standardized set of metrics and performance measures will improve the decisions for power system operational performance, as well as, help manage the cost of the variable renewable supplies being added to the grid over the coming years. Renewable production metrics may also better inform the decision points for planning new renewable additions, planning operational replacement capacity, as well as, locating and sizing integration resources. For example, new intelligent inverters are capable of provided dispatchable reactive power (volts-amperes reactive, VARs) with distribution feeders to improve system voltage and stability.

Background

Power System Operations, prior to initiating the renewable resource mandate, consisted of predictable and controllable generation along with a predictable daily demand curve. Generation supply came from dispatchable resources included sources like hydro, fossil fuel, and nuclear assets. Operational use of this supply was typically planned on a daily and weekly operations based on the forecast demand that was established, Day Ahead, with an accuracy of 1 – 3 %.[2] Generator supplies were scheduled for hourly production quantities and their service. Supply interruptions due to mechanical failure were infrequent and planned for with adequate replacement supply reserves. Unpredicted and infrequent interruption did occur for some limited generating sources between months of steady and consistent operation. This historical type of operation is changing with the new variable sources of renewable supplies that possess limited controllability and therefore can and do interrupt operation without notice, multiple times a day on a regular, non-predictable basis.

The scheduling and forecasting accuracy in both demand and supply sources are being changed to a more dynamic and unpredictable nature to account for the collection of variable energy resources with limited controllability, on all levels of the system. The increase in unpredictable deviations from scheduled energy production needs (either under or over producing) can cause significant energy imbalances which directly impacts effective and efficient management of the power system. These imbalance conditions can result in unacceptable system frequency deviations[3] and grid over loads, along with unplanned voltages beyond acceptable voltage

[2] The forecast accuracy of load prior to the deployment was performed with an accuracy of 1-3% (DA-Actual) as shown on the CAISO Market Performance Planning Forum, page 38. **http://www.caiso.com/Documents/Agenda-Presentation_MarketPerformance-PlanningForum_Jan20_2015.pdf**

[3] Unacceptable frequency deviations occur when system supply deviates over schedule and system frequency approaches 60.1 Hz or when supply deviates under schedule and system frequency approaches 59.65 Hz. Both are frequency limits that can cause involuntary supply or demand interruption.

tolerances[4]. These frequent deviations are typically referred to as threats to system reliability and can harm customer equipment due to power quality deviations from specifications. As such, we must begin to change how we monitor, plan for and operationally respond to these less predictable dynamic conditions which are growing in size and frequency on the power system.

The electric utility industry incurs ever-increasing legislation and regulator orders to maximize the supplies of renewable power – greater than 20%, 33% and 50%. Many technical studies have been done and continue to be done to analyze the long term effects of renewable supplies. It is clear that additional operational studies and analysis will be needed to assess the minute-to-minute volatility imposed by the new supply sources and degradation of flexibility margins inherent in the existing system. In order to plan for this on-going system transformation toward a much more variable and unpredictable supply source, it is clear that the industry must understand and measure actual performance while adapting to the new system dynamics and changes to its capabilities. To successfully achieve this complex transformation we should consider the development of production measures and metrics which can be used to evaluate the positive or negative impacts of the new renewable sources and quantifying the mathematical characteristics of each project and resulting portfolios ***prior to such new resources being acquired.*** In adding to the portfolio of renewable energy by utilities in California, there are choices and different options which should be considered.

Metrics and Measures

There is a need for a standard set of metrics to mathematically describe the system change to variable supply resources. These metrics would help alleviate the problems being experienced by planning and operational staffs managing these variable supplies within their power systems. This would assist in the evaluation and redesign of the power system, planning for the right resources to be added to the system so as to not negatively impact the reliability of the system and have unexpected or under estimated integration costs which show up later after the new plants are built. The acquisition of the most appropriate renewable resource can have the effect of averaging-down system issues which have been created by the purchasing of renewables for the sake of meeting a RPS, Renewable Portfolio Standard, or other goals without deploying the metrics addressed herein and weighing the value of the addition to the portfolio in terms of price and system reliability. Had such a method been deployed in the early years of acquiring renewable resources, the CAISO "Duck Curve" would look different today to the benefit of ratepayer pocketbooks and system reliability.

These production characteristics may be described in the following metrics:

- **Capacity Factor:** (Existing Metric)
  Maximum actual energy provided by a project portfolio ***divided*** by the maximum capacity of the project;

[4] System Voltages are also affected by supply deviations which can cause voltages to exceed +/- 5 %, the locally regulated limit, which may cause damage to customer equipment if exceeded. System overloads if left unmanaged for over 15-30 min., NERC limits, can also result in damage to the system equipment and cause unplanned outages to customers.

- **Relative Supply Variability, RSV**: (New Metric)
  Standard deviation statistics of the variable supplies by project, portfolio, and Balancing Authority;

- **P>5% Production**: (New Metric)
  Greater than 5% production in continuous operation. Used in the Balancing Authority daily unit commitment process;

- **P>25% Production**: (New Metric)
  Greater than 25% production in continuous operation. Used in the Balancing Authority daily unit commitment process;

- **Maximum Deviation range**: (Future metric)
  Maximum 1-15 min and hourly deviation (+ & -) that must be mitigated by a Balancing Authority, by project, portfolio, and by Balancing Authority;

- **Max Ramp Speed range**: (Future Metric)
  The maximum rate of supply changes (+ & -) over a
  1-15 min period and over an hour by project, portfolio and Balancing Authority;

- **Over Supply Energy/Capacity range** (Future Metrics)
  The amount of energy and capacity range required, avoiding unnecessary disposal of excess electric energy. This metric could be developed after further experience with over supply operational periods now forecast.

These new metric characteristics measured at different intervals of time will provide the grid designers and operators the necessary information to quantify deviations. Matched with the necessary flexible resources can mitigate the grid impacts and effects of the disruptive production deviation from schedule presented by intermittent supplies. This will be critical when the overall deployment of renewables is increased to higher levels upwards of 33% and 50%, which in California appear to be floor amounts. It will also be important for merchant suppliers and grid operators to plan and consider alternative projects (i.e. renewable resource packages) that can either decrease the deviation magnitude, occurrence and speed or better manage these metrics which would result in lower portfolio deviation and cost of integration, thereby creating more competitive and useful resources.

For grid engineers and operators, a standard set of performance metrics can help them plan for operating conditions, as well as, help design the system to ensure safety and reliability as defined by the NERC. This includes balancing supply and demand and helping plan the overall network so as to not overload grid components and maintain system voltages, and system frequency within acceptable tolerances, also NERC and Public Utility Commission, requirements.

Grid Operations Requirements for a controllable supply system

Maintaining the balance between supply and demand and correcting imbalances within very tight operational tolerances is critical to the reliability of the system. In order to maintain system stability, and frequency, a consistent supply of electricity must be maintained over the entire system to assure customers a reliable constant power source. This is accomplished in the WECC[5] by Balancing Authority areas in control of generation' planning and scheduling generation supply are necessary to serve the forecasted system demand. In addition to several balancing standards, there are over one hundred other standards that must be maintained by Balancing Authorities and their operational crews to ensure the reliability of the system every minute of every day.

Requirements of NERC, North American Electric Reliability Corporation and WECC, the Western Electric Coordinating Council

NERC defines the Balancing Authority Supply Balancing Requirements[6] necessary to maintain grid stability and power system reliability under all operating conditions. Constantly meeting demand with supply amounts is a much greater challenge for grid operators with greater deployment and variable production renewable sources being added to the grid. Reducing the size and frequency of supply variation is critical to safely operate the Grid, prevent line over-loads, maximize investment effectiveness, and ensure sufficient supply equal to demand for energy at all times.

Consequences of a power system where supply does not equal demand

Imbalances on the power system are managed by Balancing Authorities using dispatched market replacement energy or by moving their dispatchable resources to return overall supply to equal demand. If overall supply is not equal to demand the power system experiences system frequency less than 60 Hz for insufficient supply cases and frequency more than 60 Hz when supply is greater than demand for a period of time. Having more intermittent sources added to the system makes the real-time job of the Balancing Authority more difficult. It also increases the need for faster, flexible and more responsive controllable generation and demand management tools to keep the system in balance as required by NERC and WECC.

Should system frequency drop due to a corresponding drop in renewable supply or other generating resource to a level of 59.65 Hz in the WECC, customers and their demand will be automatically separated from the system and wide area outages may result. Similarly, should system frequency increase above 60 Hz due to an oversupply condition in response to unplanned-for generating sources, renewable or other, generation sources will be separated from the system in an uncontrolled operation until the frequency rise is arrested. These very bad events are referred to in grid operations as off nominal frequency events which can severely impact customer service.

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[5] WECC, Western Electric Coordinating Council; https://www.wecc.biz/Pages/results.aspx?k=Regional%20Standards

[6] NERC Reliability Standards, http://www.nerc.com/pa/stand/Pages/ReliabilityStandardsUnitedStates.aspx?jurisdiction=United%20States

Grid Operations: Early renewable supplies in operation

The power system prior to the addition of large-scale renewables was operated in a planned and controlled manner. Customer demand was forecasted and planned with some accuracy along with the controlled resources to meet this demand for every hour of the coming day of operations. Most operating conditions were predictable and plans covered extreme and unplanned for events.

This predictable world of operating the grid has changed for today's system operators and designers and it continues to change toward a more dynamic form of operations given the less predictable intermittent nature of renewables including wind and solar generating sources. Managing this complex system supply and demand balancing to successfully meet NERC standards is a challenge at roughly 20% renewable energy portfolio standards, RPS. Such RPS policies are typically based upon and average percentage requirement for a year. This presents even greater system stability and reliability challenges to system operators as periods of operating time will far exceed the average RPS percentage value, thereby dramatically increasing variability magnitude of supply deviations as steady spinning sources are displaced and removed.

Below is a chart showing the day ahead, hourly forecast error (DA schedule-Actual), or deviation from hourly schedule experienced by CAISO operations staff from solar and wind collective supplies on the CAISO grid in 2014.

Figure 1a: Collective CAISO Solar Production (DA schedule-Actual MW)

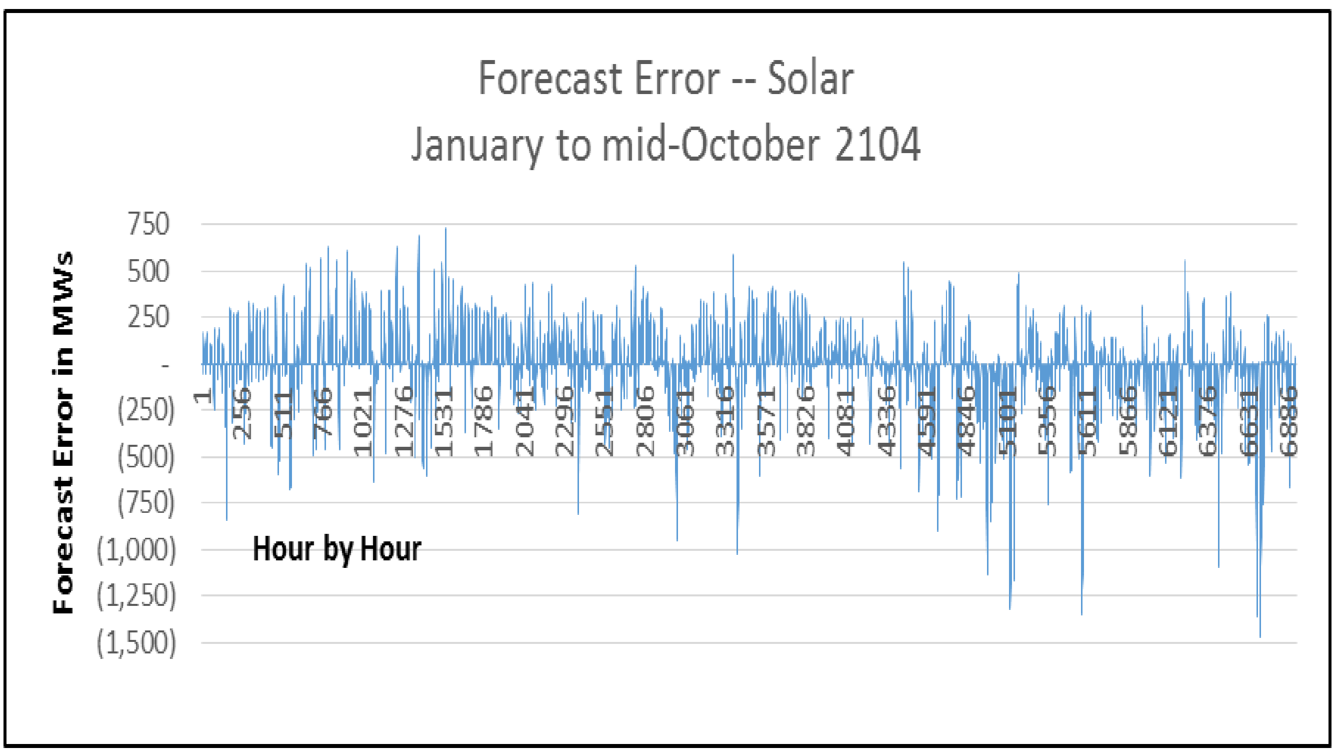


Figure 1b: Project Solar Production

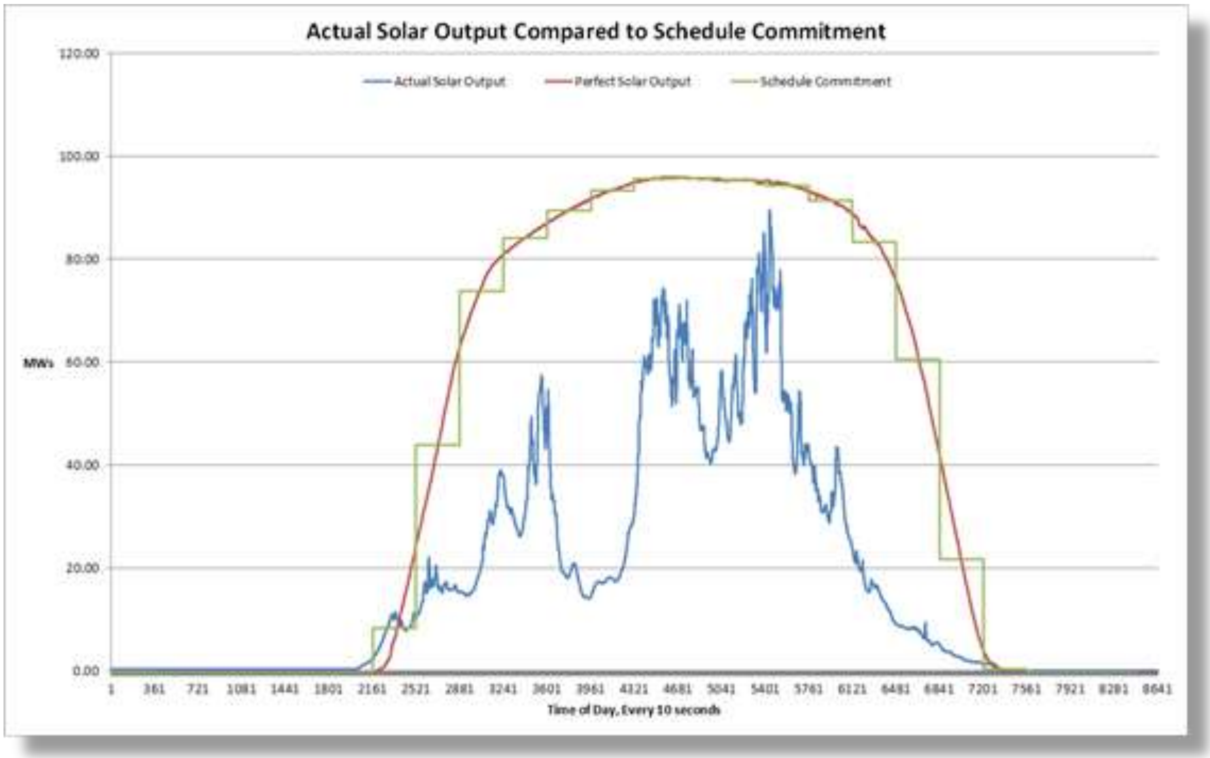
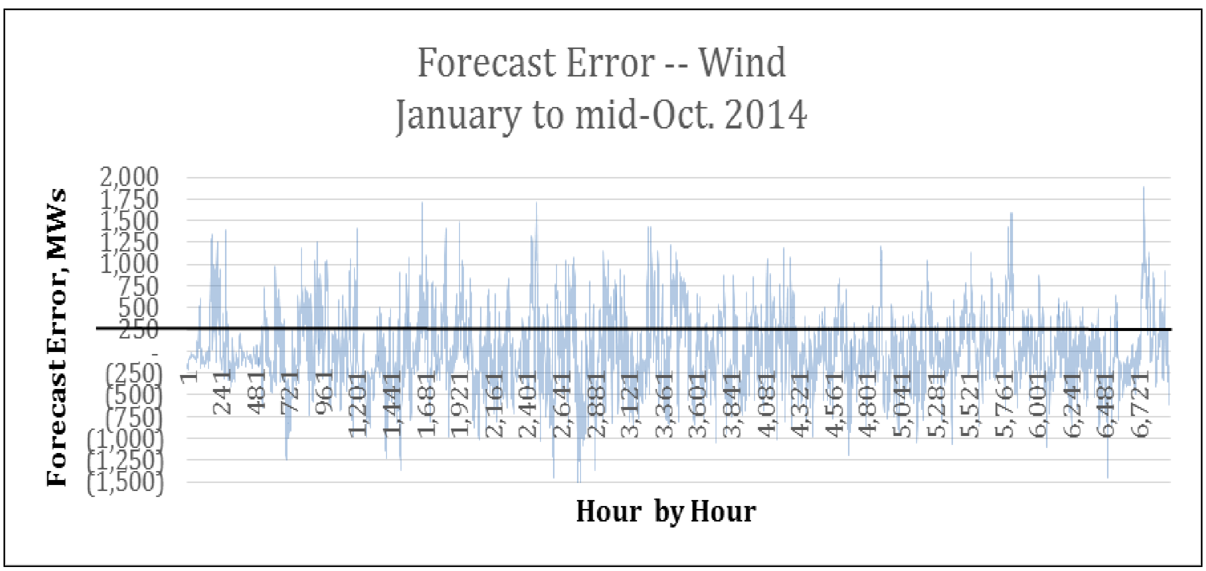


Figure 2: Collective CAISO Wind Production (DA schedule-Actual MW)



At this point in the transformation of the power system, the decision to site new renewable sources has been a local or state based decision. This decision has not yet included interstate renewable supplies which may provide geographic diversity benefits to real –time operators. With the increase in supply variability grid operators can see that in order to manage the in hour deviations from schedule and the large production ramps in the morning and early in the evening that even more new "flexible generation and rapid energy assets" are needed.

There are more underlying questions that need to be asked and are not yet answered: "Will we be able to maintain NERC Operating standards with an annual RPS average 33% of energy supplied from renewable sources such as wind and solar and their real-time production disruptions?" "What will the grid and grid operators need in the way of tools and equipment to accomplish this task of balancing supply and demand with in tolerance and safely at 33%, 50%?" and "How can we design the grid to create resilience to maintain the necessary supply balance while supporting this rapid growth of renewable energy?"

The deviations from forecast / schedule shown in the current production curves of both the CAISO wind and solar aggregate supplies show that the challenges to maintain the supply equal to demand has already reached significant levels. The standard deviation from forecast for both solar and wind is close to or exceeding 400 MW. More study of in-hour deviations at the second-by-second resolution of data is needed for solar production curves in order to produce applicable metrics for comparison. In addition, the maximum deviations experienced over the time frames shown in figures 1, and 2 indicate that the deviations exceeded 1000 MW on numerous occasions in the 2014 Hourly CAISO data. Understanding the likelihood of supply deviations, the magnitude and speed, of location specific renewable supply changes is important to Balancing Authorities and their grid operators so that operational plans and decisions can help them in managing the power system and to avoid damage to customer equipment and loss of service continuity.

After studying, engineering and operating power systems in the WECC for the last 30 years, I have seen and designed the grid with the expansion of the transmission and distribution systems, the expansion of conventional generation, co-generation, and the early stages of the transformation to variable renewable generation in the current time. The missing element associated with this stage of development is being able to measure and effectively design for the less predictable production performance and forecast the delivery performance of the new renewable based supplies coming onto the grid. Establishing measures and metrics for their performance is critical to answering the questions regarding how much and what type of renewable supply can safely be added to the power system and with what system modification. Appropriate performance metrics would help plan for the addition and comparison of the differences in alternative supply sources. Measuring and quantifying geographically diverse resources has its benefits over same location renewable sources with similar temporal variability.

Studies by the University of Wyoming and other observations

For some time now electric utilities have been adding renewable resources to the Western U.S. power system. Studies have been done which have shown that some types of renewable resources are very intermittent while others are much less variable. In addition, the production curves of some of these resources are unpredictable and not collectively consistent. These production characteristics need to be described in mathematical and statistical terms going forward.

The University of Wyoming is beginning the process of describing the volatility of renewable sources and portfolios in mathematical terms that are consistent in measurement. This is so that the different types of renewable sources on the grid can be used to numerically compare the volatile natures of the existing and proposed projects and their effects on the portfolios and balancing authorities. These metrics, with terms that define the effect of supply disruption, may possibly be used to evaluate the integration costs of different projects being proposed. This type of evaluation of projects should be an effort of future study.

In 2014 Dr. Jonathan Naughton at the UW was commissioned by the Wyoming Infrastructure Authority to study the "diversity effects" of adding Wyoming wind resources to the California portfolio of wind and solar sources, the Variable Energy Resources, online at the time. It was also at this time that researchers began developing the terms that could describe the volatility change of the two geographically diverse renewable resources when combined. The results of this work began with statistical descriptions of the existing and proposed projects. The findings were clear that a standard set of metrics is warranted to effectively describe the differences in supply sources and their effects on existing portfolios and the grid.

Table 1 shows the results of adding a Wyoming wind resource versus adding more California renewable sources. The table also shows the effects of the relative supply variability, Relative Variability, by combining Wyoming wind with California renewables. The results clearly show that combining the two geographically diverse renewable sources produces a significantly lower probability of variation, RSV, than a single source from California only within the CAISO BA.

Relative Variability in this analysis is similar to volatility measures, which are calculated for stocks and mutual funds in the stock market. A higher standard deviation of either is not necessarily a good thing but must be acknowledged. In Table 1, the California only portfolios show that a non-diversified portfolio can result in a very high Relative Supply Variability relative to a diversified portfolio of Wyoming wind combined with the current California portfolio. With regard to the operation of the power system, a less dynamic and less variable production supply would yield a more predictable and reliable system in the long run.

More stable and predictable returns are good for investors, as are more constant production levels for operating the power system. In this case we have included indicators of constant production or $P>5\%$ and $P>25\%$ of the maximum capacity. Higher profits or higher returns are good for investors, as are higher constant production levels for operating the power system. In this case, Table 1 shows that diversification can improve or increase the constant production from the current California levels. This risk mitigation will in turn lead to a more efficient and lower cost power market which is beneficial to end use customers. It should be noted these indicators point out the need to address all operational concerns, such as the daily over-generations conditions that are still developing in grid operations for California.

Table 1 CA and WY Production Metrics

% Installed Capacity				Capacity Factor	Relative Variability	P>5%	P>25%
CA 3	CA 5	WY 1	WY 3				
100%				0.240	1.03	0.67	0.39
	100%			0.266	1.08	0.62	0.41
		100%		0.440	0.81	0.80	0.59
			100%	0.482	0.77	0.79	0.64
50%	50%			0.242	0.97	0.71	0.40
50%		50%		0.333	0.61	0.91	0.64
50%			50%	0.359	0.61	0.90	0.67
	50%	50%		0.342	0.65	0.89	0.64
	50%		50%	0.371	0.64	0.89	0.68
		50%	50%	0.462	0.65	0.90	0.71
25%	25%	25%	25%	0.340	0.54	0.95	0.69

Table 1 Notes:

1) Relative Variability and Relative Supply Variability are interchangeable terms in this report.
2) All metric values in Table 1 are normalized to the Maximum Capacity interconnected as shown in the UW Analysis

Table 2: CA Renewable Build versus CA+WY Supply Diversity

	% Installed Capacity					Capacity Factor	Relative Variability	P>5%	P>25%
Description	WY1	WY3	CA W	CA S	CA G				
Current CA	0%	0%	42.2%	48.2%	9.6%	0.344	0.59	1.00	0.63
CA + CA 33%	0%	0%	35.1%	54.1%	10.8%	0.348	0.62	1.00	0.60
CA + WY 33%	13.3%	13.3%	31.0%	35.4%	7.1%	0.365	0.43	1.00	0.77

This index value, the relative variability, or RSV can be used as an indicator of the potential benefits to improve production performance characteristics of a renewable portfolio. It can also provide valuable information to help evaluate different options of projects an existing renewable portfolio. Production metrics may also provide a means of estimating the flexible capacity and characteristics needed or avoided in the operational decision making processes.

Table 2 shows that when California continues to increase its renewable supply solely with instate resources that the relative variability increases, which in turn must be matched by conventional resources to reduce the supply imbalance and volatility. Conversely should

California add Wyoming wind to its existing portfolio, the opposite happens, the relative supply variability is reduced by a significant amount. This is clearly an indication of integration benefit for the improvement in reliably of the system. In addition, this will likely result in the reduction of replacement energy and reduction in the operating effort required to restore the supply to its schedule.

This analysis process starts with data collection of projects and portfolios in different geographic areas; then analyzing and determining the performance metrics for projects, portfolios; and followed by arranging combinations of proposed projects with portfolios to result in the desired reduction of relative variability / probability, and capacity factors for the optional plans.

Wyoming Infrastructure Authority, University of Wyoming Study of Wind Diversity and Supply Quality

The following metrics were the first attempt by WIA and UW to determine the terms through which we can measure and mathematically quantify the diversity supply side benefits of combining Wyoming wind with California wind and solar. Some of the terms include:

- **Relative Variability, RSV**: This is the standard deviation of the interconnected supply source. This is shown in Table 1 under relative variability column.
- **Capacity Factor**: The term that demonstrate the energy produced MWH divided by the max possible production MW or Interconnected capacity;

These metrics have now been expanded to the four metrics *capacity factor*, RSV, Relative Variability, P>5%, and P>25% that are better representative of the variable nature of the solar and wind production curves and the balancing requirements that are being managed by the Balancing Authority. Measuring these quantities and other new metrics over time and determining the growth rates of each as a function of installed capacity will help us understand where the power system is and give us a more qualitative means of describing its production performance.

Once established, these qualifying metrics will be available to Balancing Authorities for planning system operations to satisfy the need for integration capacity to manage the power system. These metrics may also be used by merchants buying new renewable capacity and engineers planning their power systems to meet reliability standards in both the planning and operating time periods when additional conventional generation capacity is needed or fast response storage systems are needed.

The improvement in each of these terms or characteristics would lead buyers from the current measured quantities and would support the actual benefits in physical performance terms. This is a starting point for discussion and evaluations of different renewable supply sources, as we further study the geographic characteristic differences in wind resources in California and Wyoming.

Process for monitoring and assessing renewable production performance metrics

Understanding these metrics and how they have changed over time is important to be able to determine the interconnection of greater quantities of renewable sources on the systems. The additions of volatile production sources are a concern in regards to balancing requirements and system stability.

The study and quantification of system metrics should be categorized and compared by individual project and the portfolio of resources interconnected to a grid system area. The resolution of data being collected for analysis should be also be focused on hourly, as well as, down to the 15 minute and 1 minute levels, due to the observations of very vast production deviations in both direction for solar and other intermittent supplies.

All utility scale generating resource projects interconnected to the grid provide a forecast and an associated schedule for production for the following day to the Balancing Authority. On the grid controlled by a Balancing Authority and managed by an energy market, a day-ahead schedule is a financial commitment for the resource scheduler in the market for the associated production. Any deviations from the scheduled amount of power will be corrected by the Balancing Authority and market during real-time operations as required for NERC standards. The costs of managing such deviations are typically assigned to the project resource creating the imbalance or deviation from schedule.

Most of the current operational focus dealing with variable production supply is to improve the operational forecast and schedule accuracy. There are, however, other options to reduce this forecast and scheduling error prior to connecting these resources to the grid, which is to have a more informed resource selection process which utilizes performance metrics that include the benefits of locational diversity, and portfolio performance. Other related operational processes could benefit by utilizing this information as well.

Production deviations from scheduled amounts have increased with the increase in total capacity of variable supplies. This is seen in the Relative Supply Variability in Table 3 increasing from current levels 0.59 to increased RSV of 0.62 at 33% CA resource projections. However, if the increase to 33% renewables was supplied by Wyoming's Geo diverse wind supplies the Relative Supply Variability would have been reduced to only 0.43 a positive performance improvement.

Table 3: California plus Wyoming Wind Results

	% Installed Capacity					Capacity Factor	Relative Variability	P>5%	P>25%
Description	WY1	WY3	CA W	CA S	CA G				
Current CA	0%	0%	42.2%	48.2%	9.6%	0.344	0.59	1.00	0.63
CA + CA 33%	0%	0%	35.1%	54.1%	10.8%	0.348	0.62	1.00	0.60
CA + WY 33%	13.3%	13.3%	31.0%	35.4%	7.1%	0.365	0.43	1.00	0.77

Table 4: CA–WY Supply Resource Additions

Technology	CA 33% Portfolio Additions			CA/WY 33% Portfolio Additions		
	Capacity (MW)	Ann. Gen. (GWh)	Capacity Factor	Capacity (MW)	Ann. Gen. (GWh)	Capacity Factor
CA Geo/Bio	513	3642	0.810			
CA Solar	2563	6297	0.280			
CA Wind	757	2061	0.311			
WY Wind				3000	12000	0.457

Process for Using Renewable Production Metrics

Developing metrics for the many renewable resource locations and types over the time periods and in the time intervals necessary requires focused attention to detail. The collection of information must be time-based and cover the range of values.

To clearly understand any issues that must be addressed from intermittent production sources, we can begin the analytical process by comparing any new source data to the existing entity portfolio performance metric. This will require starting with data verification by location of existing projects that are already interconnected to the power system. Once the metrics characterizing actual portfolio deviation from forecast, schedule or average productions are determined, the information can be used as a base for planned new projects. The accuracy of both the existing source data and possibly the meteorological data used from any new sources should be understood.

As for a Balancing Authority, the determination of baseline metrics, one should make clear the geographic areas within the Balancing Authority and what part of the grid are being measured and calculated. The metrics could then help the Balancing Authority and grid participants both understand the limits of variable supply and its associated variability. The Balancing Authority can manage this by mitigating resources such as batteries and or conventional generating resources.

Comparing new sources and having a standard basis for comparison is the path included in the studies being completed at UW. Their comparison of the normalized relative variability shown in Table 2 clearly shows the reduction of variability using Wyoming wind versus California solar sources.

These relative differences using hourly production data could be the start of step #2 that could be used to estimate the integration cost reduction using a geographic diverse resource to manage the supply variation. This information is important for grid operation staffs as they plan for meeting the variations in real-time operations as well.

New or planned projects that do not have a history of production yet available to them can utilize similar technology resource production curves located in the similar location to estimate the metrics likely to be produced. The use of project site meteorological data over time can also be a source of information that can be used to project the likely metrics and production characteristics. The existing similar renewable source metrics could then be scaled up or down, as necessary, in proportion to the new resource being proposed. The resource could then be added to the portfolio of the proposed buyer to determine the net effects economic and operational on the buyer's portfolio. Evaluation of geographically diverse resources such as wind on the eastern side of the Rocky Mountains has shown significant benefits that could help with the renewable integration in California as compared with California only renewables as shown in the deviation metrics of Table 3.

The data and analysis from UW has shown that time periods used for calculating performance metrics should be set to reflect the production changes of the supply source. For instance, solar sources can disrupt and resume productions in seconds and minutes, therefore the metric calculations reflecting the variations in supply should be analyzed in no more that 5-15 minutes for purposes of comparison. A source such as wind may have a longer period, but for comparison sake should be standardized to the same time interval. The 5 minute standard deviation versus the hourly, daily, seasonal deviations provide the evaluator and operator different yet important pieces of information.

Utilizing metrics to gage the performance of the different renewable sources will allow the purchaser and owners of such projects to more accurately value each production source in the market before and after it is operational. Analysis of renewable supply past production performance for a 3 to 5 year look back could be very insightful to planning the further build out and for determining the plans to purchase renewables in similar locations or better fitting resources with complementary production metrics. Looking forward it is possible to see that additional metrics may be necessary to characterize certain other characteristics such as contribution to system oversupply conditions, demand curve correlation, maximum/minimum voltage deviations and overload conditions. These metrics will require further study as they may involve other power system traits that are evolving with the system transformation. Understanding how these performance metrics change over time will also be an area that will require study.

Conclusion

Production metrics and formulaic measures will establish a consistent mathematical process and means for comparing and measuring the quality of all renewable projects and portfolios. These metrics may also be used to project the changes in production performance when projects are added to a portfolio. As today's grid is transformed, we must begin this process of characterizing the new production sources so that we can achieve the objectives of reducing Green House Gases and do so in a technically and an economically viable manner. Metrics are used by financial planners and traders to describe the variation and volatility of stocks in the stock market. Similarly the engineers and power traders must learn to use similar techniques to characterize its world of investment and stable grid design and operation.

An analysis subsequent to this report should be conducted to deploy the metrics defined herein at a point in the past (five years is recommended) to determine the impact on the infamous "Duck Curve" had such metrics been adhered to in the past. Such an analysis would address some lessons learned and assure the customers on the CAISO System of a lower cost, more efficient and reliable power resource.

The author of this Report acknowledges that significant efforts, analyses, studies and other work has been conducted by both the CAISO and utilities on the grid. These new metrics described herein would contribute to both the work that has been accomplished and that is ongoing in California.

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Jim Detmers is currently a Consultant and Company Advisor to several firms designing and developing technology and resources for the new sustainable power system. He is deeply involved in the integration of variable production renewable supplies to the power system at all levels from the customer to the Bulk Power System. Mr. Detmers is a former Chief Operating Officer (COO) and Vice President, Operations of the California Independent System Operator Corporation (CAISO), where he was responsible for the reliable and compliant operation of the transmission system that delivered electricity to over 30 million Californians. The California ISO service area encompasses the majority of the state's high voltage wholesale power grid and is the largest member of the interconnected electric transmission system of the western region. Jim was employed at the CAISO for 13 years leading the organization and industry thru startup and establishment of the wholesale power markets. He served in leadership positions over the organization's Engineering and Operations Divisions. Before joining the California ISO in 1997, Mr. Detmers worked for Pacific Gas and Electric in a variety of engineering leadership roles within the Electric Transmission and Distribution Operations area of the corporation. He also worked for the Modesto Irrigation District and Westinghouse Electric. Mr. Detmers received his Bachelor of Science in Electrical Engineering from the California Polytechnic State University, San Luis Obispo in 1986. He is an alumnus of the Haas School of Business Executive Development Program and is a Licensed Professional Electrical Engineer in the State of California. Mr. Detmers is a member of the Institute of Electrical and Electronics Engineers and a former board member of the Western Electricity Coordinating Council and Western Systems Coordinating Council.

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