CALIFORNIA ISO WIND GENERATION FORECASTING SERVICE DESIGN AND EXPERIENCE

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ABSTRACT

This article outlines a major California ISO-led project that aims incorporating wind power generation into the California Energy Market and providing state-of-the-art forecasting services for participating wind power producers. Wind power is a highly intermittent resource that cannot be bidden competitively in a traditional market due to scheduling problems. The paper describes a unique market arrangement that makes this possible. The central part of this initiative is a provision that deviations between metered and scheduled energy for participating intermittent resources will be averaged across a calendar month, and paid or charged based on the weighted average market clearing price over that month. On March 27, 2002, the Federal Energy Regulatory Commission (FERC) approved the Proposal and ordered the California ISO to report on the program in 16 months. This success was a result of a collective effort of a large group of people representing different organizations and working together in the Intermittent Resources Working Group. Without pretending that the authors were the only ones who made the entire job, this paper provides a brief description of the principles developed by the Group, which allow the wind power producers to exploit all benefits of the California Energy Market.

This paper focuses on the California ISO experience gained with wind generation forecasting requirements and methods. A sufficiently accurate hour-ahead forecasting is important to make wind power producers competitive as energy market bidders. It was found that, for the newly designed market principles, the monthly forecast error bias is even more important than the error itself.

The article discusses the California ISO experience with its persistence forecasting models and newly developed bias self-compensation scheme. Among different studied forecasting methods, one has demonstrated the best performance – the Box-Jenkins ARIMA model. It has been determined, that the model is able to provide relatively good forecasts for the next hour and 1 hour ahead. For these time intervals, the total ISO-metered generation is predicted with the mean absolute error (MAE) below 3 and 8% of the maximal observed generation correspondingly. This makes the persistence models suitable for the short-term wing generation forecasting and real-time dispatch in the Grid Control Centers. At the same time, for participating wind generators bidding in the hour-ahead market under the California ISO scheduling timeline, the forecast must be made for an operating hour, which is 2.5 – 3.5 hours ahead. The California ISO persistence model keeps MAE below 9% of the maximum observed generation, which constitutes 37% of the average California generation. These numbers can become even worse if the production is forecasted for a particular Project rather than for the aggregate production of several wind farms. This result allows making a conclusion that the local meteorological forecasts and plant physical/statistical models should be employed in the site-oriented hour-ahead wind generation forecasting. At the same time, it was shown that even with the California ISO persistence model, the required unbiased forecasting is quite possible. With the California ISO bias self-compensation scheme employed, for the year 2001, the monthly forecasting bias would be in the range from –790 to 1,110 MWh (less than 0.3% of the monthly produced energy), which results in monthly settlements below the total $70,000 for entire California. It was also shown that the bias compensation is possible without sacrificing the accuracy of forecasts.

Based on experience gained with the California ISO persistence model, a number of requirements and assessment criteria have been developed in order to select the best Vendor for providing hourly MWh forecasting services for the Projects participating in the new California ISO market structure. They are the following: (a) the model should incorporate local weather forecasts and derate data in order to minimize MAE; (b) a bias compensation algorithm should be a part of the model; (c) the algorithm should be adaptive in terms of its ability of self-tuning based on its past performance and changing generation patterns; (d) the model should provide the probabilistic confidence intervals for its forecasting errors, and (c) the algorithm should be able do detect inconsistencies in real-time production data caused by unscheduled events such as unit outages or metering equipment failures.

The hands-on experience with the California ISO algorithm also helped to work out the hardware and informational structures implementing the Project. They are also discussed in the paper.

I. INTRODUCTION

The California electricity production is heavily dependent on natural gas as a fuel. This dependence is a potential threat to California because of the possibility of shortcuts and peaking natural gas prices that could lead to catastrophic consequences. Fuel diversity in the energy sector is a critical matter for the State. In California, where environmental concerns are so strong, the clean wind power creates an especially attractive alternative to building new coal or nuclear generation power plants.

According the California Energy Commission (CEC), there are more than 13 thousands turbines installed in California. In 2000, wind generators had produced 1.27% of electrical energy in California. The American Wind Energy Association (AWEA) reports that the installed wind generation capacity in California is 1,671 MW with about 660 MW planned for installation in the near future. The Pacific Northwest Laboratory estimated that the average wind generation potential in California constitutes 59 billion kWh (which, for example, would exceed 20% of the gross system electricity production in the year 2000).

The Federal government encourages electricity production from wind farms with a 1.5% tax credit. California also offers incentives through the Existing Renewables Program ($70.2 million) and the New Renewables Program (nearly 1,000 MWh of new installed capacity is being added under this program).

In 1978, Congress passed the Public Utilities Regulatory Policies Act (PURPA). The intention of this Act was to support the efficient use of energy. PURPA required utilities to accept offers from qualifying facilities (QFs). These QFs can be cogenerators who generate electricity reusing the steam used in a manufacturing process or independently owned power plants producing electricity from wind, geothermal and other renewable sources of energy. Another type of QFs are small power producers, e.g. small hydropower plants. To receive the QF status, a generator must file an application with the Federal Energy Regulatory Commission (FERC). PURPA mandated that utilities pay QFs the avoided cost. The avoided cost calculation includes the capacity cost and energy cost. The capacity cost is the construction cost of the new generating facility. The energy cost is the cost of fuel and other variable expenses. Therefore, if a utility does not need new capacity in the near future, its avoided cost is only the energy component. With the new competitive generation build-up, the capacity cost component will be shrinking, and the QFs will be facing a reduction in their revenues.

In 1999, the California Public Utilities Commission (CPUC) permitted the avoided cost energy payments to be based on the market clearing price for qualifying facilities that elect this option. This motion was designed as a temporary measure, and it has been facing an opposition as an off-market arrangement that benefits some power producers more than the others. Current uncertainties associated with the future of the QF program excite more interest among the independent wind power producers to new forms of their participation in the energy market. It is also likely that these uncertainties are limiting the growth of investments in renewable power resources.

There are several serious obstacles for the wind power resources to become competitive bidders in the Energy Market. These are the relatively high production cost, unfavorable generation patterns when the maximum wind generation does not coincide with the maximum energy demand and market clearing price (in terms of their seasonality[1] and daily variations), and difficulties associated with the scheduling of these highly intermittent resources.

There is a strong trend toward reducing the wind power production cost. According to the Electric Power Research Institute (EPRI), the cost of producing wind energy has decreased nearly four times since 1980. The cost of energy from wind turbines in 1993 was about 7.5 cents per kWh. The CEC estimates that newer technologies can reduce the cost of wind energy to 3.5 cents per kWh. While the power produced by California's older wind turbines is not cost-competitive with other types of generation, some of the newest wind turbine designs may be able to match or beat the power prices from many coal and nuclear plants. This will make wind power more competitive in the Energy Market.

One of the promising arrangements intending to mitigate negative effects of wind intermittency and its mismatch with the peaks of market clearing price is horizontal coupling of wind power resources with pumping plants and other perspective energy storage facilities.

The intermittent nature of the wind power resource is a reality that cannot be eliminated completely. Special market arrangements and state-of-the-art forecasting tools are required to create conditions for competitiveness of the wind power in the Market. A sufficiently accurate hour-ahead forecasting is important to make wind power producers competitive as energy market bidders.

By initiative and leadership of the California ISO and the Office of Governor Gray Davis, the California Intermittent Resource Working Group has undertaken a major development in order to create mechanisms for incorporating the independent wind power producers into the California Energy Market. The Intermittent Resource Working Group consisted of representatives from the California ISO, California governmental organizations, EPRI, wind power producers, utilities and scheduling coordinators, power marketers, and associations. This initiative has resulted in unique market design arrangements[2] (Intermittent Resource Proposal) filed to FERC the Amendment 42 on January 31, 2002.

On March 27, 2002 FERC approved the proposal and ordered the ISO to report on the performance of the program in 16 months, to incorporate the technical standards for participating intermittent resources into the ISO Tariff, and to consider allowing existing intermittent resources to participate in the program.

The main purpose of this paper is to disseminate the experience that the California ISO Corporation has gained in the process of developing of its wind generation forecasting tools. The paper describes the California ISO experimental persistence model that allows providing reasonably accurate MWh forecasts for the 1-2 hours perspective. The model is being used for the real-time forecasting of the total ISO-metered California wind production and for real-time dispatch purposes. The model has been also applied for the hour-ahead scheduling timeline that requires predicting the MWh production for an operating hour that is 2.5 – 3.5 hours ahead of time. These results are also discussed in the paper. This experience helps to de-

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[1] Although in California, wind speeds are highest in the hot summer months, and approximately 3/4 of all annual wind power output is produced during the spring and summer.

[2] The California ISO Director of Compliance Mr. Eric Leuze was the Coordinator of the Intermittent Resources Working Group and Principal Developer of the new wind power market structures.

termine whether the suggested wind power settlement process is feasible, and allows formulating requirements for the state-of-the-art forecasting service. The paper also describes a special bias compensation scheme developed by the California ISO aiming to minimize dollar settlements for uninstructed deviations of participating intermittent resources from the forecast-based schedule.

Wind power is a highly intermittent resource that cannot be bidden competitively in traditional markets due to scheduling problems. The paper describes a unique market arrangement that makes this possible. The hands-on experience with the California ISO algorithm also helped to work out the hardware and informational structures to implement the Project. They are also discussed in the paper.

II. INTERMITTENT RESOURCES MARKET ARRANGEMENT

Even with the most advanced forecasting methods, the wind generation forecasting error will remain significant. Special market arrangements are needed in order to accommodate wind power resources as energy market participants. The California ISO has developed a tariff language that allows intermittent power producers to bid the forecasted generation in the market. They will not be held responsible for short-term deviations from the schedule because the suggested settlement process is based on the calendar month average deviations (the bias). The California ISO market arrangement is described in this section.

A) Opportunities and Risks for Wind Power Producers in the Existing California Energy Market

None of the existing wind generators in California is participating as a bidder in the energy market. The California wind resources are Qualifying Facilities who currently choose to exploit advantages of the Public Utilities Regulatory Policies Act and regulations of the California Public Utilities Commission as described in the introduction. At the same time, many wind power producers in California and even in the neighboring states have expressed their interest and provided strong support to the California ISO initiative that allows them either to become market players or just evaluate their opportunities there.

There are no formal limitations that prohibit wind power resources to participate in the existing California Energy Market. With the existing market structure, this, of course, would result in some very significant disadvantages and problems for the participating resources, scheduling coordinators, and the California ISO. We will discuss these issues briefly in order to contrast advantages of the new market arrangement developed by the California ISO.

Wind generators that participate in the California ISO market would be settled just as any other generating unit. A wind generator could submit an hourly schedule for their generation in the Day Ahead or Hour Ahead Markets. Deviations from this schedule would be settled based on the ISO’s market clearing price (MCP) every ten minutes. Positive deviations would be paid the decremental MCP and negative deviations would be charged the incremental MCP. Since wind generators cannot control their output to meet a firm schedule, the likelihood of significant deviations and settlements is high. Another option for wind generators in the California ISO market would be to bid in the real-time Supplemental Energy Market for incremental energy. A zero-priced bid would likely be dispatched if the real-time needs called for incremental energy, and the wind generator would be paid the incremental MCP for the metered energy from the instruction. A final option for wind generators in the ISO market would be to operate “uninstructed” for the hour. Uninstructed incremental energy would be paid at the decremental MCP.

These options are not sufficiently attractive for intermittent resources since the risk of volatile market prices and the cost of deviations from schedule is very high. While these options are still open to wind generators, the California ISO is pursuing additional penalties for both deviations from schedules and undelivered dispatch instructions at FERC which, if approved in the future, would make these options even less attractive for wind generators.

B) Objectives and Accomplishments of the California Intermittent Resources Group

By initiative and leadership of the California ISO Vice President Mr. Randy Abernathy and the Senior Policy Advisor for the Office of Governor Gray Davis Dr. Woodrow W. Clark II, the California Independent System Operator Corporation along with the California Intermittent Resource Working Group has undertaken a major development in order to create mechanisms for incorporating wind power producers into the California Energy Market. The Intermittent Resource Working Group consisted of representatives from the California ISO, California governmental organizations (California Governor's Office, California Energy Commission, Department of General Services, Department of Water Resources), utilities and scheduling coordinators (South California Edison, Pacific Gas and Electric, Sacramento Municipal Utility District, PacifiCorp, Automated Power Exchange) associations (American Wind Energy Association, Independent Energy Producers Association, California Municipal Utilities Association), wind power producers (Seawest, Florida Power and Light Power, Oak Creek Energy Systems), marketers (ENRON) and environmental organizations (Center for Energy Efficiency and Renewable Technologies), research institutions (Electric Power Research Institute, Consortium for Electric Reliability Technology Solutions), and consulting companies.

The Intermittent Resources Working Group has been pursuing the following objectives:

- Accommodation of intermittent resources without degradation of California ISO reliability;
- Incorporation of safeguards and incentives to minimize potential cost-shifting to other market participants;
- Provision of a transmission and market access framework though which intermittent resources can secure project financing, and
- Minimization of California ISO market costs that arise from the difficulty of scheduling intermittent resources;

The Group has developed a Consensus Intermittent Resources Proposal that stated the following principles and action items:

- Initiate a forecasting project to develop high quality forecasts for the day-ahead and hour-ahead scheduling and real-time forecast for ISO operations;
- Establish calendar month settlement periods to net deviations across the intervals and to be settled at the weighted-average price for the month;
- Create a Forecasting Work Group to monitor performance of intermittent resources and impacts on ISO system and costs;
- Eligible intermittent resources will sign ISO agreements, install ISO meters and a DPG[3], pay a forecasting fee and schedule consistent with a state-of-the-art forecast;
- Intermittent resources will not be charged for Deviation Replacement Reserve. Deviation Replacement Reserve and Imbalance Energy costs will be assigned to Imbalanced Load, and
- Congestion charges may still apply to Intermittent Resources.

C) FERC Filing and Implementation Process Status

Based on the Consensus Proposal, the California ISO worked out changes to its Tariff Language included in Amendment 42 filed at FERC at the end of January 2002[4]. On March 27, 2002, FERC approved the Amendment and ordered the ISO to report on performance of the program in 16 months, to incorporate the technical standards into the ISO Tariff, and to consider allowing existing intermittent resources to par-

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[3] Data Processing Gateway (DPG)

[4] Amendment 42 can be found at http://www2.California ISO.com/pubinfo/FERC/filings/

ticipate in the program. The ISO filed the Eligible Intermittent Resource Protocol in the Compliance Filing for the FERC March 27 Order on April 11, 2002.

Based on provisions of Amendment 42 and experience gained with the California ISO prototype forecasting algorithm, the California ISO developed a detailed specification of the Intermittent Resources Scheduling Project and an RFB for Wind Generation Forecasting Service[5]. The RFB was distributed to some leading providers of these services. At this stage, the bids of potential Vendors have been received and evaluated. A Short List of Bidders has been already selected, and currently the California ISO is evaluating results of testing of the short-listed Bidder algorithms with the test datasets developed by the ISO. Future steps include selection of the winning Vendor, request approval for expenditures, awarding the contract, acceptance testing of model, and release of the scheduling process to production. The entire system is expected to be operational in September 2002.

D) Benefits of the New Market Arrangements for Participating Projects

With the Intermittent Resource Proposal, deviations between metered and scheduled energy for Participating Intermittent Resources (PIRs) will be averaged across a calendar month, and paid or charged based on the weighted average market clearing price (MCP) over that month. This provision reduces the volatility of the ten-minute interval settlements. If the forecasting model used for hourly forecasting is statistically unbiased, the chance of under-scheduling Energy generation in each hour will be very similar to the change of over-scheduling, and the expected value of deviations between scheduled and metered energy is zero.

No charges for deviation replacement reserve or for the cost of out-of-market purchases at prices above the MCP would be assessed against PIRs that schedule in accordance with the ISO approved forecasts. A wind generator that schedules generation in the ISO markets without participating in the Intermittent Resource Proposal would be subject to these charges along with deviation charges.

The aim of the proposed provisions is to reduce the volatility of settlements, but the expected value of the net settlement should represent neither a subsidy nor charge to PIRs. Given that the model that is used for hourly forecasting is statistically unbiased, the ISO does not expect significant deviations from PIRs, and therefore the expected value of allocation adjustments for deviations is expected to be small or zero.

E) More Details of the New Settlement Process

The central part of the proposed intermittent resources market is the new settlement process. This section describes details of this process. The scheme of charges and payments related to the intermittent resources scheduling process is shown in Figure 1.

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[5] The RFB document can be found at http://www.California ISO.com/pubinfo/notices/index.html. Mr. Scott Jercich was managing development of the RFB.

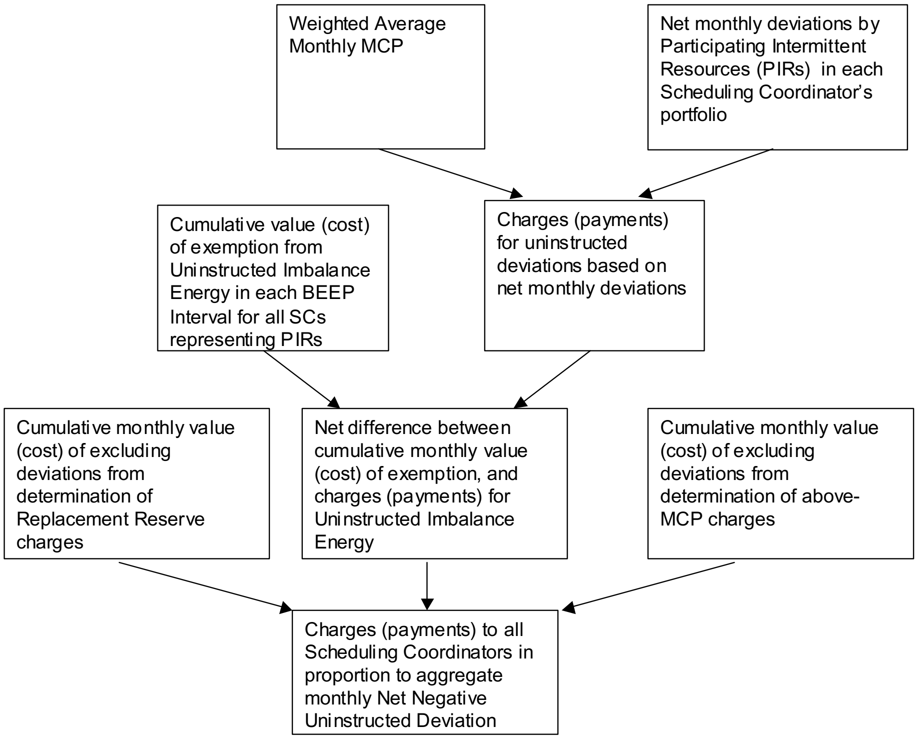

FIGURE 1. CHARGES/PAYMENTS RELATED TO PARTICIPATING INTERMITTENT REOURCES

Uninstructed Imbalance Energy

The ISO will settle uninstructed imbalance energy associated with deviations by PIRs on a monthly basis. Settlement of uninstructed deviations in each BEEP[6] interval for any Scheduling Coordinator (SC) that does not have PIRs in its portfolio will be unchanged from the current settlement process. There will be no change in the amount of neutrality charges assigned in the aggregate or to individual SCs in any BEEP interval. The amounts that would have been paid by SCs on behalf of PIRs, if deviations by such resources were instead settled as the Tariff provides for other generating units, will be aggregated and tracked in a "balancing account" for all PIRs in the ISO Control Area.

Concurrently, the actual deviations by each participating wind generator will be tracked in each BEEP interval, and netted across each calendar month. Each Scheduling Coordinator will then be paid or charged for the aggregate net deviations in its ISO Control Area portfolio at a single weighted average BEEP interval ex post price for the month, where the weights are quantities of energy instructed at each BEEP interval ex post price. These payments or charges will be aggregated and netted against the amount in the "balancing account" described above.

Assuming that energy forecasts are unbiased, the expected net difference between what would have been charged or paid in relation to deviations by PIRs, and what is actually charged or paid, will approach zero.

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[6] BEEP (Balancing Energy Ex Post Pricing) Scheduling Software Application is used to dispatch resources for real-time imbalances between actual load and generation, and scheduled load and generation. BEEP selects the most economic resource available to restore deficient Regulation and Operating Reserves, as necessary, to maintain system reliability in accordance with WSCC and NERC criteria. The BEEP interval is 10 minutes.

Deviation Replacement Reserve

Replacement reserve is assigned first to the sum of overscheduled generation and under-scheduled load in each SC's regional portfolio. If the amount of replacement reserve to be allocated exceeds the total overscheduled generation and under-scheduled load, then that difference is assigned pro rata to all load (excluding exports).

Under the new scheduling process, charges for replacement reserve to SCs that do not represent participating wind generators will be unchanged. Charges to each SC representing PIRs will be adjusted to exclude the deviations by PIRs from the calculation of 'overscheduled generation' in each such SC's regional portfolio. This adjustment will result in a net charge in each settlement period equal to what the Scheduling Coordinator would have experienced if metered energy from PIRs, adjusted for losses, were equal to scheduled energy in every hour.

These adjustments may increase or decrease the charge to SCs representing PIRs. As with the difference in settlement of uninstructed imbalance energy noted above, the expected value of these adjustments is zero. The actual value of these adjustments will be accumulated across all SCs representing Participating Intermittent Resources, and settled monthly as described below.

Above-Cap Energy Costs

As part of the PIR scheduling process, the ISO will modify the recovery of in-market and out-of-market instructed imbalance energy that exceeds the market clearing price (MCP). This modification would limit the charges that are assigned to SCs with net negative uninstructed deviations. The treatment of participating wind generators is compatible with these changes.

Charges to Scheduling Coordinators that represent participating wind generators for above-MCP costs would be adjusted to eliminate the effect of deviations by participating wind generators. As with the adjustment to settlement of Replacement Reserve, these adjustments may increase or decrease the obligation for above-MCP costs. These adjustments will also be accumulated across all Scheduling Coordinators representing PIRs, and settled monthly as described below.

As with the adjustments associated with replacement reserve, the adjustments to charges for above-MCP Energy costs imposed on SCs representing PIRs are expected to be zero in any given hour since the forecast will be designed to be unbiased.

III. DESCRIPTION OF THE INTERMITTENT RESOURCES SHEDULING PROCESS[7]

The PIR scheduling process involves four entities – the ISO, the forecasting service, the wind generation operators and their SCs (see Figure 2). Following describes the role of each in the process.

A) The ISO

The ISO plays the central role in the PIR scheduling process. The ISO collects, from each wind generation operator, local meteorological data necessary for use by the forecasting service via a secure Internet connection. This data will be submitted by the wind generators to the ISO twice per day. This data includes wind speed, wind direction, barometric pressure, temperature, humidity and precipitation. The ISO will also collect wind generation output data via the EMS system[8]. The ISO will collect generation derate information from SLIC[9] and forecast accuracy data resulting from a separate audit function.

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[7] The development of the Intermittent Resources Scheduling Process was managed by Mr. Scott Jercich.

[8] This data is provided to Energy Management System (EMS) via the wind generators Data Processing Gateway (DPG).

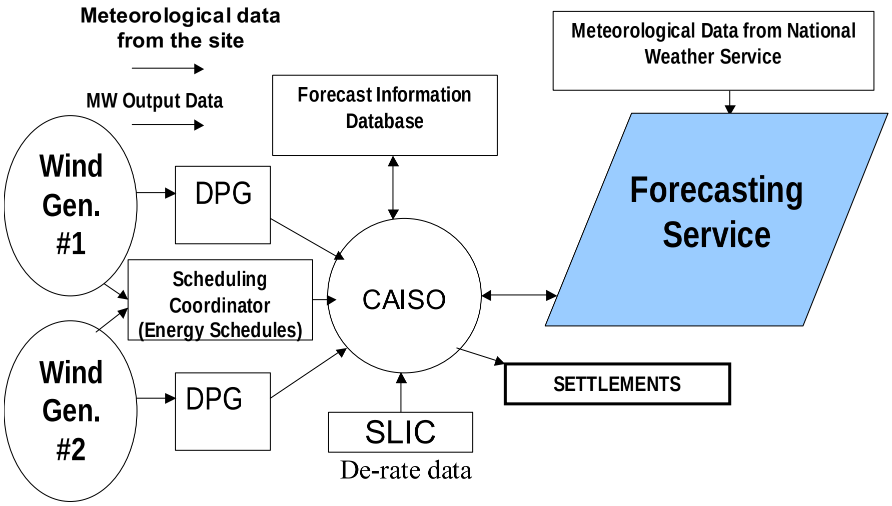

FIGURE 2. DATA FLOW FOR WIND GENERATION SCHEDULING PROCESS

The ISO will provide to the forecasting service ("Vender") a data update every ten minutes. This information will include the most current local meteorological data, wind generation operator data and forecast accuracy data. The forecasting service will provide to the ISO, each hour on the half hour, a seven-hour rolling generation forecast for each wind farm. In addition, the Forecasting Service will provide by 8:30 a.m., for each wind farm a day ahead forecast for each hour of the following day. These day ahead and hour ahead forecasts will be transferred by the ISO to the wind generations via secure Internet connection.

The ISO Operations will carry out a pre-settlements validation process for the energy schedules that are submitted to the ISO by the SCs. This process will flag the energy schedules that are to receive special treatment under the new PIR scheduling process. More specifically, Operations will compare the generation forecasts prepared by the forecasting service for each operating hour with the energy schedules submitted by eligible, participating wind generators for the same operating hours. If the forecasted generation and the generation submitted in the energy schedules are equal, and no adjustment bids or supplemental energy bids are included with the schedules, then these resources will be flagged in the energy schedules and passed on to settlements for favorable treatment, with respect to uninstructed deviations, for those operating hours.

The California ISO will maintain a Forecast Information Database containing the following data:

- Location-Specific Generation Forecasts
  - -Hourly
  - -Daily
- Met Data by Location
  - -Wind Speed
  - -Wind Direction
  - -Barometric Pressure

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[9] This information is put into the Scheduling Logging for the ISO of California Database (SLIC) by the ISO outage coordinators after notification of a derate by the wind generation operators.

    -Temperature
    -Humidity
    -Precipitation

- Wind Gen Operator Data
- Generator Output
- De-rate Information
- Forecast Accuracy Data

B) Forecasting Service

A Vender will be hired by the ISO to prepare and provide to the ISO by 8:30 a.m. a daily energy generation forecast for each PIR. This day ahead forecast will be for each operating hour of the following day. The Vender shall also provide a forecast for each of the next seven operating hours no later than 30 minutes prior to the beginning of the operating hour. The forecasts prepared by the Vender will be kept confidential with integrity intact and submitted on a timely basis to the ISO in the proper data format.

The Vender is expected to be able to receive data from the ISO every 10 minutes and provide location-specific, day ahead and hour ahead forecasts on a timely basis. The Vender must provide this service to the ISO on a 24-hour per day, 365-day per year basis. The maximum level of unavailability allowed by the Vender during any 30-day period for data receipt and forecast transmission capability is two hours. The average daily outage duration must be less than 30 minutes in any 30-day period, with an extreme daily outage event never lasting longer than 1.5 hours in the same 30-day period.

The ISO will transfer PIR meteorological tower data, generator output, and derate information to the Vender every ten minutes. This information, together with other information collected by the Vender, shall be used by the Vender to prepare timely generator output forecasts to the ISO.

The Vender must provide complete documentation, including the model specifications, data and variable transformations used. Calibration of the forecast model by the Vender will be necessary over time to assure accurate, unbiased results. All statistics relevant in evaluating the quality of performance of models used and the relevance of each variable included will be published by the Vender. The Vender will develop a plan describing how the model results will be recorded, presented, and used to refine and focus additional model specifications and testing.

C) Wind Generation Operators

The wind generators must provide aggregate wind farm generator output data, along with local meteorological data, to the ISO. Each wind generation operator must install a DPG unit that transmits this data to the ISO's EMS system. In addition, the wind generation operator must continue to submit units derate information to the ISO via SLIC.

The wind generator operator will receive from the ISO by 8:30 a.m. each day a day ahead forecast for each Operating Hour of the next day. In addition, the wind generator will receive each hour on the half hour a rolling, seven-hour generation forecast. If the wind generators wish to receive favorable treatment with respect to uninstructed deviations, they must submit hour ahead energy schedules (via their Scheduling Coordinator) that match the hour ahead forecasts provided by the ISO.

D) Scheduling Coordinators

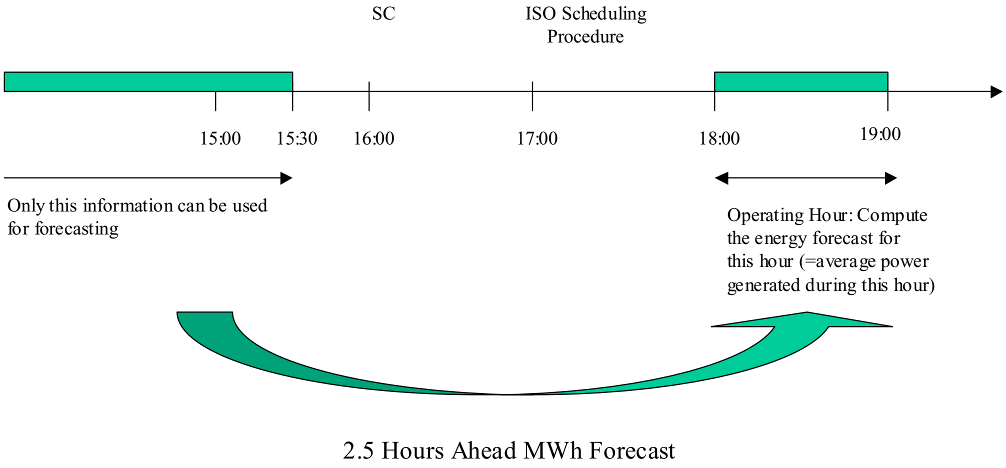

FIGURE 3. THE CALIFORNIA ISO HOUR-AHEAD SCHEDULING TIMELINE

SCs will submit energy schedules to the ISO via the SI system[10]. If these Schedules are to receive favorable treatment with respect to uninstructed deviation charges, the generation portion of the Schedule must match the forecasted generation provided to the wind generation operator by the ISO. Figure 3 represents an example of the California ISO hour ahead scheduling timeline. According to the timeline, the forecasting service provider must actually submit the "hour-ahead" forecasts to SCs 2.5 hours before the operating hour begins. Therefore, the forecasts for an operating hour, which begins at 2.5 hour and ends at 3.5 hour ahead of time, are the most important forecasts influencing the hour-ahead market.

For the day-ahead market, as it was indicated above, the most important forecasts are the ones that estimate the MWh production for the operating hours starting at 15.5 hour and ending at 39.5 hours ahead of time. The rest of forecasts are used for some ancillary purposes. For example, the shorter-term forecasts (less than 2.5 hours ahead) can be used in the internal ISO real-time generation re-dispatch process. The longer-term forecasts can be used by SCs and the ISO as a substitute for missing hourly forecasts when the actual forecasts are not available due to whatsoever reason.

IV. THE CALIFORNIA ISO PROTOTYPE FORECASTING ALGORITHMS

The California ISO has developed several prototype algorithms for short-term wind generation forecasting. The next operating hour and one hour ahead algorithms are oriented for internal ISO needs which include real-time generation re-dispatch purposes. The 2.5 hour ahead algorithm was a proof-of-concept development as a prototype for the future wind generation services.

To make the best choice, different methods and combinations have been analyzed. In all cases, the forecasts were based on retrospective data (that is the purely persistence models were used). No meteorological or generator status data was involved at this initial stage. The methods tested include the random walk, moving average, exponential smoothing, auto-regression, Kalman filtering, "seasonal" differencing, and

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[10] The Scheduling Infrastructure (SI) Database is the chief interface between Cal-ISO and market participants. It performs data collection and validation and publishes market information.

Box-Jenkins models. The Box-Jenkins ARIMA model has been finally selected. The model's coefficients were adaptively adjusted to achieve the best accuracy.

A) Objectives of the California ISO Prototype Algorithms

By developing the prototype algorithms, the California ISO has been pursuing the following purposes:

- Gain hands-on experience with different forecasting techniques in order to select state-of-the-art wind generation forecasting services in the future.
- Work out the necessary technical background for incorporating wind power resources into the California Energy Market (including the uninstructed deviations settlement procedures most favorable for wind power producers).
- Evaluate the expected forecasting errors and biases.
- Convince all interested parties that the forecast accuracy and bias allow wind generation to enter California Energy Market as a competitive bidder.
- Obtain knowledge and experience required for developing the intermittent resources scheduling process, data requirements, metering, informational flowcharts, forecasting accuracy audits, etc.
- Get a stronger position in negotiations with the potential wind generation service providers.
- Develop a reserve strategy for an alternative in-house forecasting tool development.

B) Description of the California ISO Forecasting Algorithm

Parameters:

0 - Current moment of time
$-t$ - t hours before the current moment
$+t$ - t hours after the current moment
G_t - Actual generation at the moment t, [MW]
g_t - 1 hr generation prior the moment t, [MWh]
f_t - Forecasted 1 hr generation prior the moment t, [MWh]
$e_t = f_t - g_t$ - Forecast error, [MWh]
δ - Data sampling interval, [hrs]; e.g. $\delta = {}^{1}\!/_{900}$ hr (= 4 sec.)

Algorithm:

1. For every clock-ten-minute interval (e.g. $t = 0$ may correspond to '31 Jul 2001, 20:30:00').
2. Check generation data availability at $t = -1, -1 + \delta, -1 + 2\delta, \ldots, -\delta, 0$

3. If any data point $G_{-k\cdot\delta}$ is missing, substitute it with the approximation $G_{-k\cdot\delta} = G_{-K_1\cdot\delta} + \frac{k-K_1}{K_2-K_1}\left(G_{-K_2\cdot\delta} - G_{-K_1\cdot\delta}\right)$, where K_1 and K_2 is the closest pair of healthy data points, $K_1 < k < K_2$

4. Compute 1-hour generated energy for the current moment and the moment which is 10 minutes behind $g_0 = \delta \sum_{i=1}^{1/\delta} G_{-i\cdot\delta}$, $g_{-0:10} = \delta \sum_{i=1-1/6}^{1/\delta-1/6} G_{-i\cdot\delta}$

5. Compute forecast errors $e_0 = f_0 - g_0$ and $e_{-0:10} = f_{-0:10} - g_{-0:10}$

6. Compute the mean absolute error for the past *T* hours: $MAE = \frac{1}{T}\sum_{i=-T+1}^{0} |e_i|$, where *T* is the observation interval, e.g. $T = 100$, i.e. 4 days.

7. Compute the forecasting error standard deviation $STD = \sqrt{\frac{1}{T-1}\sum_{i=-T+1}^{0}\left(e_i - \frac{1}{T}\sum_{i=-T+1}^{0} e_i\right)^2}$

8. Compute the past-month forecast bias $B_0 = \sum_{i=-24*D+1}^{0} e_i$, where *D* is the number of days in the current month

9. Apply the adaptive optimization procedure to adjust model coefficients at Step 10. The procedure is described in the sequel.

10. Compute the 2.5 hour ahead forecasted growth/decline factor[11]

$$
\begin{array}{l}
\phi_{+3:30} = [g_0 + \\
\left.\begin{array}{l}
\left.\begin{array}{l} +\alpha_{-0:10}(g_0 - g_{-0:10}) \\ +\alpha_{-3:30}(g_0 - g_{-3:30}) \end{array}\right\} \text{Autoregression Component} \\
\left.\begin{array}{l} +\beta_0 \cdot e_0 \\ +\beta_{-0:10} \cdot e_{-0:10} \end{array}\right\} \text{Moving Average Component} \\
\left.\begin{array}{l} +\alpha_{-26:20}(g_{-22:50} - g_{-26:20}) \\ +\beta_{-22:50} \cdot e_{22:50} \end{array}\right\} \text{"Seasonal-" Day Before Component}
\end{array}\right\} \text{Modified ARIMA Model} \\
+\gamma \cdot \hat{B}_0] / g_0 \quad \} \text{Bias Compensation Component}
\end{array}
$$

where $\alpha_{-0:10}, \alpha_{-3:30}, \beta_0, \beta_{-0:10}, \alpha_{-26:20}, \beta_{-22:50}, \gamma$ are adjustable model coefficients. The coefficients are selected adaptively using a process described below. The new bias compensation component $\hat{B}_0$ is described below in Section devoted to the bias compensation scheme.

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[11] Note that we forecast for an hour that starts 2.5 hour ahead, and ends 3.5 hours ahead. That is why, according to our notations, we use index "3:30" for the look-ahead quantities.

11. Apply the following limiting rule to the 2.5 hour ahead forecast growth/decline factor:

$$\overline{\phi_{3:30}} = \begin{cases} \Phi_{\max}, \text{ if } \phi_{3:30} > \Phi_{\max} \\ \phi_{3:30}, \text{ if } \Phi_{\min} \le \phi_{2:30} \le \Phi_{\max} \\ \Phi_{\min}, \text{ if } \phi_{3:30} < \Phi_{\min} \end{cases}$$

Coefficients $\Phi_{\min}$ and $\Phi_{\max}$ are also adjustable parameters.

12. Determine the 2.5 hour ahead forecast: $f_{3:30} = \overline{\phi_{3:30}} \times g_0$

13. Apply the following limiting rule to the 2.5 hour ahead forecasts:

$$\overline{f_{3:30}} = \begin{cases} G_{\max}, \text{ if } f_{3:30} > G_{\max} \\ f_{3:30}, \text{ if } 0 \le f_{2:30} \le G_{\max} \\ 0, \text{ if } f_{3:30} < 0 \end{cases}$$

where $G_{\max}$ is the wind generation capacity[12].

14. Wait until the beginning of the next 10 clock-minute interval, and go back to Step 1.

C) Bias Self-Compensation Scheme

The bias compensation scheme aims to minimize the look-ahead forecast bias $B_{3:30} = \sum_{i=-24*D+4.5}^{3:30} e_i \rightarrow 0$ [13] by introducing an additional term $\gamma \cdot \hat{B}_0$ into the modified ARIMA model. *D* is the number of days in the current month. Coefficient γ is adjusted using the model coefficient selection procedure described in the sequel. This Section describes how $\hat{B}_0$ can be computed.

Statistical Metric

Let e_t [MWh] is the forecast error computed for the *t*-th hour, $t = ..., -2:30, -1:30, -0:30$. We introduce the RMS of $\boldsymbol{e_t}$ as the square root of the second non-central moment over the population of these variables:

$$\mu = rms(e_t) = \sqrt{\frac{1}{24 \times D} \sum_{t=-24 \cdot D+4.5}^{-0:30} (e_t)^2}$$

This metric can only be zero if the biases for all hours are zero. In order to better understand the metric, the following expression can be derived:

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[12] In the above expression, zero thresholds can be replaced by negative numbers representing the maximum on-site load.

[13] Here we explain how the summation is conducted: e.g. for $D = 30$,
$B_{3:30} = \sum_{i=-24*D+4.5}^{3:30} e_i = e_{-715:30} + e_{-714:30} + ... + e_{-0:30} + e_{+0.30} + e_{+1:30} + e_{+2:30} + e_{3:30}$, that is the sum is determined for round 1 hour increments of time starting from the beginning time.

$$\sigma^2(e_t) = \tfrac{1}{24\times D} \sum_{i=-24D+4.5}^{-0:30} \left[e_t - avg(e_t)\right]^2 = \tfrac{1}{24\times D} \sum_{i=-24D+4.5}^{-0:30} (e_t)^2 - \left[avg(e_t)\right]^2$$
$$\Rightarrow \mu^2 = \sigma^2(e_t) + \left(\tfrac{1}{24D}\right)^2 B_{4:30}^2 \qquad (1)$$

where $\hat{B}_0 = -\sum_{i=-24*D+4.5}^{-0:30} e_i$ and $\sigma(e_t)$ is the population (non-sample) standard deviation of the e_t.Therefore, the suggested metric directly depends on the average forecast error over all hours of the analyzed one month period (i.e. systematic forecast error) and the variance of the individual average errors with respect to the systematic error. By minimizing $\boldsymbol{\mu}$, we will minimize both the forecast accuracy (variance of $\boldsymbol{e_t}$) and bias. Experiments showed that in order to achieve a proper balance between minimization of the variance and bias, it is necessary to emphasize the bias related component in the suggested metric. This can be done by modifying the metric in the following way:

$$\mu^2 = \sigma^2(e_t) + c \cdot B_0^2$$

where $c >> \left(\frac{1}{24D}\right)^2$ is an experimental coefficient, e.g. in our studies $c = 0.9$.

Self-Correction Scheme

The idea behind the suggested self-correction algorithm is to modify the forecasted wind generation for the look-ahead hours in order to compensate for the accumulated bias. Mathematically, expression for the look-ahead bias can be written as follows:

$$B_{3:30} = \sum_{i=-24*D+4.5}^{3:30} e_i = \sum_{i=-24*D+4.5}^{-0:30} e_i + \sum_{i=+0:30}^{3:30} e_i = -\hat{B}_0 + e_{+0:30} + e_{+1:30} + e_{+2:30} + e_{+3:30} \to 0$$

In this expression, we can evaluate $\hat{B}_0 = -\sum_{i=-24*D+4.5}^{-0:30} e_i$ related to the past moments of time, but we have no idea about the future forecast errors for $t \geq +0:30$. We can only attempt to compensate for the known part of the bias by correcting our forecasts (and therefore the forecast error) by a value $\gamma\hat{B}_0$. The last term in the expression for the growth/decline factor at Step 10 of the forecasting algorithm is introduces to provide such compensation.

E) Adaptive optimization procedure for selecting model coefficients

Experiments conducted for different time intervals have demonstrated that the optimal model coefficient $\alpha_{-0:10}, \alpha_{-3:30}, \beta_0, \beta_{-0:10}, \alpha_{-26:20}, \beta_{-22:50}, \gamma$ and $\Phi_{\min}, \Phi_{\max}$ are different. Therefore they should be selected adaptively using a self-adjustment process described below.

The adaptive procedure aims to minimize the objective

$$\mu^2 = \sigma^2(e_t) + c \cdot B_0^2 \to 0$$

by varying model coefficients $\alpha_{-0:10}, \alpha_{-3:30}, \beta_0, \beta_{-0:10}, \alpha_{-26:20}, \beta_{-22:50}, \gamma$ and $\Phi_{\min}, \Phi_{\max}$. Note that metric μ is determined for the past moments of time, where the actual generation g_t is known. Each time the model coefficients are changed, the forecasting procedure must be repeated for all points from

$-24*D+4.5$ to $-0:30$ in order to determine the updated "could be" forecasts f_t for all these past moments. The corresponding changes of the bias metric μ show the effect of the coefficient variation.

In our experiments, the coefficient search was performed by manual one-by-one adjustments of the model parameters. It has been discovered that the objective function has a very complicated shape that makes it difficult to solve by traditional gradient-based optimization methods. Our suggestion is to use one of the more robust modern artificial intelligence optimization methods such as particle swarm, genetic algorithms, taboo search, simulated annealing, etc.

V. FORECASTING RESULTS

The prototype forecasting tools were tested using the actual ISO-metered wind generation data in the California Control Area stored in the California ISO Plant Information (PI) Database. The experiments were repeated for each month of the last year with and without the bias compensation scheme activated. In each case, the model coefficients were adjusted by applying a manual optimization procedure. When the bias compensation scheme was disabled, the objective was to provide a minimum MAE. When it was enabled, the objective was to minimize the suggested bias metric $\mu^2 = \sigma^2(e_t) + c \cdot B_0^2 \to 0$.

A) Typical Forecasting Process and Forecasting Accuracy

The developed prototype tools include the next-hour, 1-hour, and 2.5-hour algorithms.

Next Hour and Hour-Ahead Forecasting

The first two tools are oriented for the real-time needs of the ISO dispatch personnel. The tools automatically compute the next and 1-hour ahead forecasts every 10 clock-minutes, and additionally evaluate the mean absolute error (MAE) and the range where the generation is expected to be with 95% probability. The next hour and 1-hour MAEs were found in the ranges 4– 35 MWh and 7– 98 MWh correspondingly (out of the max observed generation 1,252 MWh). This constitutes less than 3 and 8 per cent of the maximum observed generation correspondingly[14]. Figure 4 presents a graphical image of the California ISO short-term forecasting display as is at 8:40 a.m. on May 29, 2002. The display consists of one table and two graphics.

The table in Figure 4 provides information on the current point (MWh generation for the period from 7:40 a.m. to 8:40 a.m.), as well as forecasted parameters for the next hour (8:40 a.m.– 9:40 a.m.) and 1 hour ahead (9:40 a.m.–10:40 a.m.). For the current hour, the MWh generation is reported as 129.6 MWh. It can be compared against generation forecasted 1 hour before (174.5 MWh). This comparison gives the forecasting error 44.8 MWh. For one next hour, the actual generation is not known. It is forecasted as 84.3 MWh. The expected mean absolute error is determined based on the specified number of past observations, and it is projected into the future as 37.4 MWh. Similarly, the standard deviation is evaluated as 51.2 MWh. The standard deviation gives an opportunity to approximately evaluate the 95% confidence interval for the forecasting error as ±102.5 MWh = ±2×STD – we assume that the forecast error is unbiased and normally distributed. These limits allow quantifying the 95% range where the generation is expected to be during the next hour: from 0 to 186.7 MWh. The upper graphics displays the actual generation for the last day (solid dark blue line) as well as its next hour forecasts (pink dots). The light blue marks show the 95% error confidence range. Note how this range is changing with time depending on the observed standard deviation of the forecast error. The 1-hour ahead information is presented in the table and lower graphics in a similar way. The only difference is that the MAE and STD are much more significant. This indicates that the persistence model is approaching the limit of its look-ahead capability.

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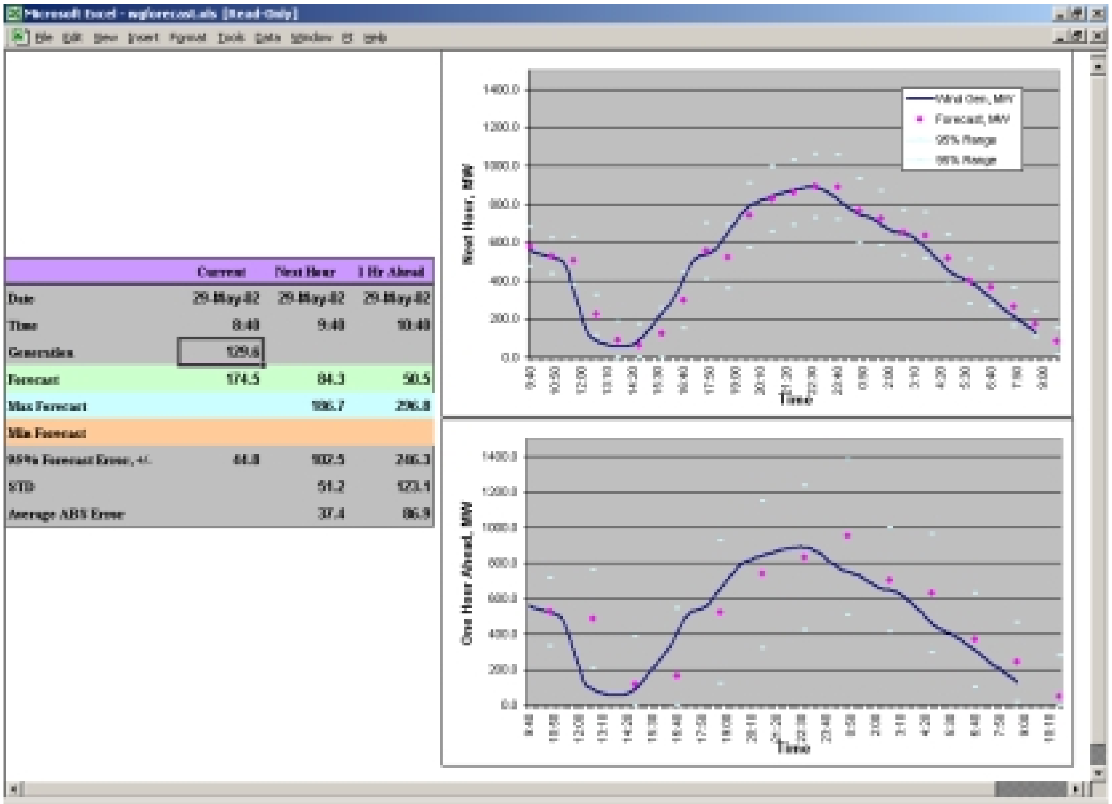
[14] See the discussion on the ways in which the MAE can be presented in the next Section. Here we use the maximum observed generation instead of the total generation capacity.



	Current	Next Hour	1 Hr Ahead
Date	29-May-02	29-May-02	29-May-02
Time	8:40	9:40	10:40
Generation	129.6		
Forecast	174.5	84.3	90.5
Max Forecast		186.7	296.8
Min Forecast			
95% Forecast Error, +/-	44.8	102.5	246.3
STD		51.2	123.1
Average ABS Error		37.4	86.9

FIGURE 4. THE NEXT HOUR AND 1 HOUR AHEAD FORECASTING DISPLAY

2.5 hour ahead forecasting

The 2.5-hour tool is developed for the PIRs and SCs participating in the hour-ahead market. The 2.5 hour timeline corresponds to the timeline currently used at the California ISO (Figure 3). This algorithm gives the MAE below 120 MW (less than 10% of the maximum generation 1252 MWh).

TABLE 1. ACCURACY, BIAS, AND EFFECT OF SELF-COMPENSATION BY MONTH

Month	Monthly Bias, MWh		Mean Absolute Error, MWh		MAE, % of Max Generation		MAE, % of Average Generation	
	Without Self-Correction	With Modified Self-Correction	Without Self-Correction	With Modified Self-Correction	Without Self-Correction	With Modified Self-Correction	Without Self-Correction	With Modified Self-Correction
January 2001	-117.7	-20.0	57.3	57.9	7.0%	7.1%	35.9%	36.3%
February 2001	245.0	388.3	66.4	67.8	6.7%	6.8%	31.8%	32.5%
March 2001	-1165.1	-275.8	104.2	101.5	8.9%	8.6%	24.7%	24.1%
April 2001	-701.6	-787.8	114.7	107.8	9.2%	8.6%	19.7%	18.5%
May 2001	1215.1	498.2	119.5	107.8	9.8%	8.8%	21.9%	19.8%
June 2001	554.1	81.0	119.0	107.6	9.6%	8.7%	19.4%	17.5%
July 2001	2087.4	1109.5	103.3	86.3	9.5%	7.9%	18.0%	15.1%
August 2001	379.2	201.1	95.9	81.5	8.1%	6.9%	18.6%	15.8%
September 2001	548.6	90.4	97.0	82.4	9.2%	7.8%	25.2%	21.4%
October 2001	-434.8	18.3	75.8	76.4	7.2%	7.2%	23.5%	23.7%
November 2001	276.1	-107.1	76.8	74.1	8.7%	8.4%	36.1%	34.8%
December 2001	20.2	0.2	66.1	66.2	7.8%	7.9%	27.1%	27.2%
NET	2,906.4	1,196.2						
Monthly MAE	601.7	299.7	91.3	84.8	8.5%	7.9%	25.2%	23.9%

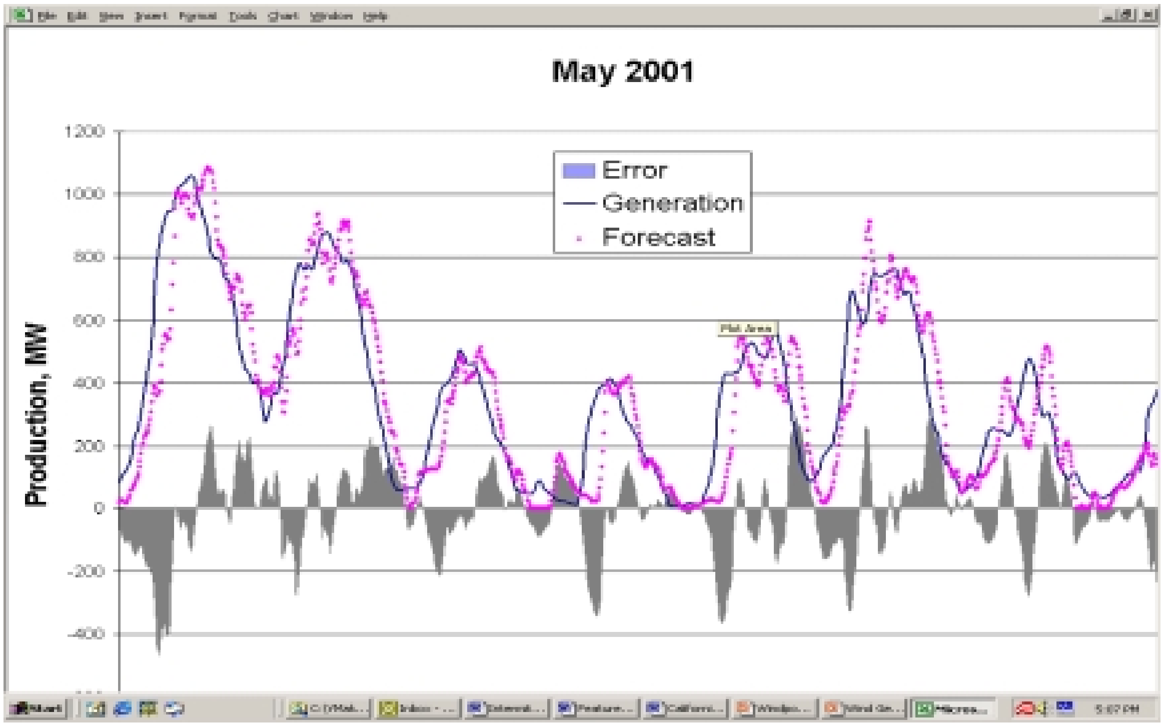


FIGURE 5. TYPICAL 2.5 HOURS AHEAD FORECASTING PROCESS

A typical 2.5 hour ahead forecasting process is shown in Figure 5. It is observed that the instantaneous forecasting error of the prototype persistence model can be rather significant (even in excess of 400 MWh). The large errors are observed when the actual generation experiences sudden rapid swings that cannot be in principle anticipated by a persistence model. Outside these ‘disturbance’ intervals the maximum instantaneous error becomes less significant (below 200-250 MWh).

Table 1 contains the monthly MAE data. The monthly MAE remains below 120 MWh, which constitutes less than 10% of the maximum generation 1252 MWh. These significant numbers clearly indicate the necessity to involve forecasted weather parameters (such as wind speed and direction) and unit derate information into the model.

B) Bias Compensation

The bias self-compensation scheme is proven to efficient in reducing the forecast bias without any increase of MAE. Table 1 contains numerical data reflecting the effects of self-compensation. It is seen that the bias was reduced in about 2 times (Figure 6), whereas the MAE remained the same if not reduced. Figure 7 shows a similar improvement achieved in minimizing the monthly dollar settlements.

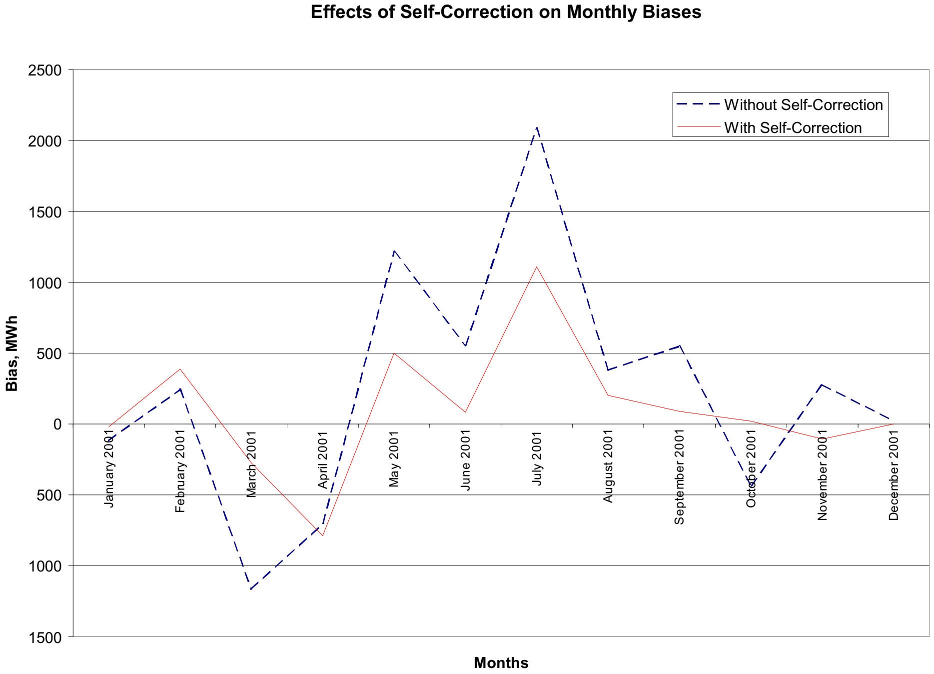


FIGURE 6. EFFECTS OF SELF-CORRECTION ON MONTHLY BIASES

C) Conclusions on the California ISO Forecasting Algorithm

- Persistence models are adequate for the next and 1-hour ahead forecasting (that is they can be used in hour-ahead California ISO dispatches)
- The forecast error for the 2.5 hour ahead forecasting becomes significant (up to 36% of average generation for one-month MAE, and 24% for a one-year MAE)
- Unbiased forecasting procedures that are essential for minimization of monthly uninstructed deviations are feasible. The developed bias minimization algorithm is effective.
- Meteorological forecasts must be included in the model in order to achieve more accurate results
- Wind generator status information is also essential
- Minimizing the HA scheduling timeline would be definitely helpful
- The persistence model requires an adaptive search for optimal model coefficient. The artificial intelligence methods are good candidates for this purpose.

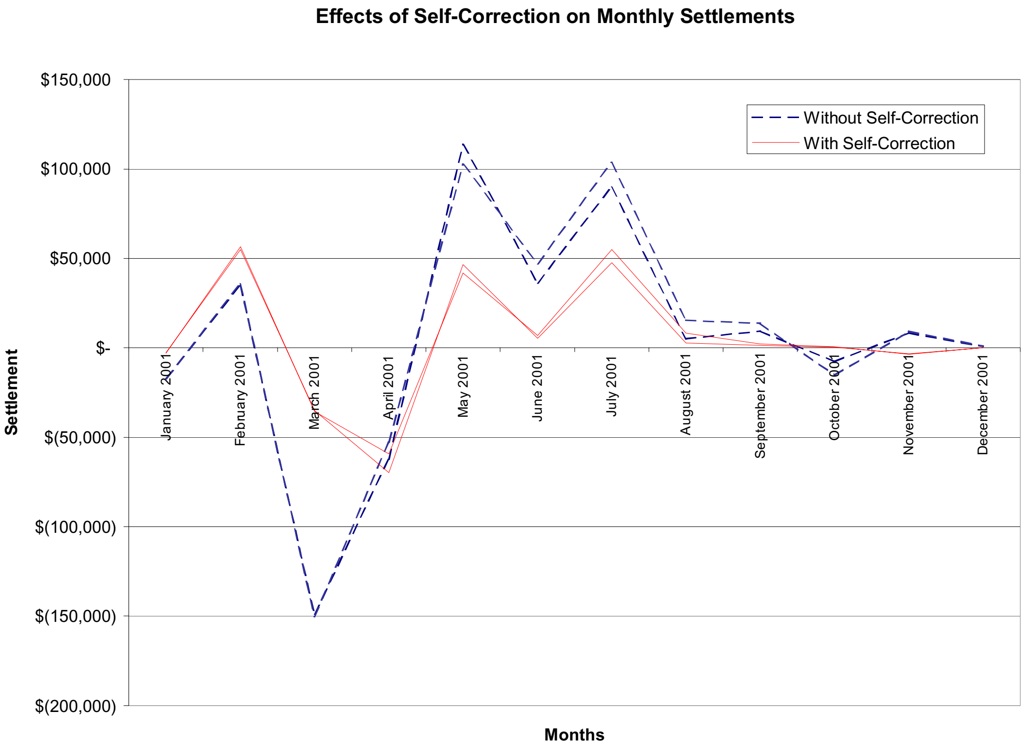


FIGURE 7. EFFECTS OF SELF-CORRECTION ON MONTHLY SETTLEMENTS

VI. ON ALGORITHM ACCURACY AND ITS IMPROVEMENT

This Section summarizes our suggestions and observations regarding the wind generation accuracy measures and ways of improvement of forecasting models.

A) Suggestions Helping to Improve Forecasting Models

- It is helpful to forecast generation increments rather than generation itself – this allows incorporating the actually observed generation as soon as it available.
- The use of 1-hour MWh production instead of MW production as a forecasted parameter creates an additional filtering (smoothing of the generation curve) that makes generation more predictable.

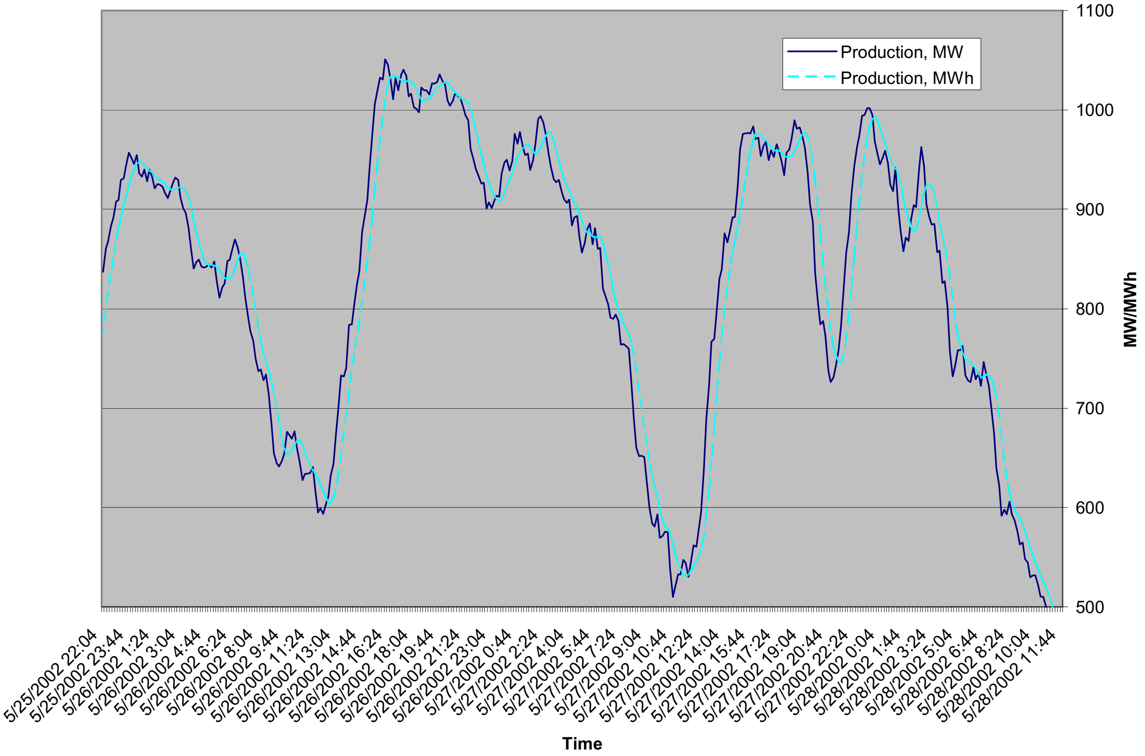


FIGURE 8. MWH PRODUCTION VS. MW PRODUCTION

Figure 8 shows an example where the ‘filtering’ process is clearly seen. The MWh production curve (dashed light blue line) is smoother than the MW curve.

- Repeating 1-hour MWh production forecasts every 10-minutes allows incorporating the most recent information regarding the generation trend and forecasting error.
- The confidence intervals for MWh generation forecasted along with its expected level help to evaluate the expected error range for the scheduling coordinators and wind farms.
- Full employment of all components in the model such as past increments of generation and observed forecasting errors (for the last hour, last 10 minutes, at the same hour last day) helps to build a flexible and adjustable model.
- Adaptive update of the model coefficients by repeating the forecast for the past observation period in order to find the best fit; the use of these dynamically updated coefficients to forecast the future generation.
- Incorporate all known constraints including the current generation capacity, zero generation level or maximum local load (as a negative generation limit), etc.
- It may helpful to limit the rates of generation changes; this rate should be also an adaptively selected parameter

B) On Accuracy Measures of Wind Generation Forecasts

One of the most commonly used measures of accuracy used in wind generation forecasting is the Mean Absolute Error (MAE). Depending on its denominator, per cent MAE can have the following forms:

$$MAE_{CAP}\ [\%] = \frac{\text{Mean Absolute Forecast Error [MWh]}}{\text{Wind Generation Capacity [MWh]}} \times 100\%$$

or

$$MAE_{AVG}\ [\%] = \frac{\text{Mean Absolute Forecast Error [MWh]}}{\text{Average Wind Generation [MWh]}} \times 100\%$$

The MAE_{CAP} is based on the total wind generation capacity of the source, while MAE_{AVG} is based on the average generation over certain period of time. These two formulas produce substantially different results. For example, in Table 1, the MAE_{CAP} remains below 9 – 10% of the total ISO-metered generation capacity while the MAE_{AVG} reaches 36.3% of the average monthly generation. While the value of MAE_{CAP} might be taken as an acceptable one, the MAE_{AVG} definitely signals significant forecasting errors. In this Section, we briefly discuss these and some other properties of MAE.

Some providers of wind generation forecasting services prefer to use the capacity-based MAE. They argue that MAE_{AVG} is increasing at lower generation levels, and that this may make a wrong impression regarding the actual magnitude of forecasts deviation from the actual generation. Our point is that the capacity-based percent MAE should be replaced by MAE_{AVG} because of the following reasons:

- The MAE capacity-based criterion may be confusing regarding the actual magnitude of individual forecasting errors. For example, even with the 9% capacity-based MAE achieved in our persistence model, individual forecasting errors frequently exceed 400 MW (out of maximum 1252 MW). This discrepancy becomes even more striking with MAE exceeding 10 – 12%. (e.g. 15% MAE_{CAP} looks like an acceptable error, but it can really correspond to 50% average deviation of forecasts from observed generation).

- Wind farms are rarely operating at their maximum capacity (the California average generation is usually 20-50% of the capacity, 30% is its mean value).

- Because the lower-range generation is more typical, it seems to be not adequate to apply capacity-based criteria.

Measures like RMS are more sensitive to the magnitude of individual MWh deviations and can supplement the MAE. Using expression (1), the RMS error can be expressed through variation and forecasting bias. The latest is very important for the suggested settlement procedure for intermittent resources participating in the California energy market.

The length of the averaging intervals for computing MAE influences the result, especially, the MAE based on the average generation. Longer intervals can hide local significant excursions of MAE. Shorter intervals give MAE that varies in a wider range. Speaking about the MAE, one should give a range of shorter-term MAEs rather than just a single number for a long-time perspective. In a forecasting process, the shorter-term MAE assessment should be dynamically recalculated using a sliding short-term observation interval (about one – three days). Instead of the MAE ranges, one can evaluate the probabilistic confidence intervals. For instance, one can determine the 95 % confidence interval for the forecasting error (this gives us an idea about the expected range of errors for future time intervals). For example, the confidence intervals can be approximately evaluated by performing the following steps:

- Suppose that the forecast error distribution is normal and unbiased.

- Determine its short-term standard deviation σ for the past 24-72 hours.

- Calculate the 95% confidence interval for the forecasting error as approximately $\pm 2\sigma$.

- Dynamically update the confidence interval as time progresses.

VII. CONCLUSION

The unique market arrangement suggested by the California ISO allows the Participating Intermittent Resources to bid in the California Energy Market. The state-of-the-art forecasting service is important for the success of the development undertaken under the California ISO leadership. Even with the prototype purely persistence model developed by the California ISO, where the monthly MAE may exceed 36% of the average generation, the intermittent resources market remains feasible. This happens because the new settlement procedure developed for participating intermittent power producers, is based on monthly averages of uninstructed deviation from the schedule. The bias compensation ideas help to further minimize the monthly dollar settlements. The California ISO anticipates significant improvements from exploiting more advanced forecasting tools developed by a leading Vender. The Venders selection procedure is already in progress. The hands-on experience gained by the California ISO helped to formulate the advanced features that should be present in the selected Vender's model. It is expected that due to these advanced features discussed in the paper, a noticeable decrease of the forecasting error will be achieved. This would allow minimizing the impacts of intermittent resources on the California ISO reserve requirements, on its real-time dispatch process, and Automatic Generation Control system.

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Yuri V. Makarov received his M. Sc. degree in Computers and Ph.D. in Electrical Engineering from the Leningrad Polytechnic Institute (now St. Petersburg State Technical University), Russia, in 1979 and 1984 respectively. From 1990 to 1997 he was an Associate Professor at the Department of Electrical Power Systems and Networks in the same University. From 1993 to 1998 Yuri conducted research at the University of Newcastle, University of Sydney, Australia, and Howard University, USA. From 1998 to 2000 he worked at the Transmission Planning Department, Southern Company Services, Inc., Birmingham, Alabama as a Senior Engineer. Currently he is occupying a senior engineering position at the California Independent System Operator, Folsom, California. Yuri's activities are around various theoretical and applied aspects of power system analysis, planning and control. Yuri has published more than 60 papers, including several books and book chapters. He supervised and mentored more than 20 graduate and PhD students in Russia, Australia, and the USA. Yuri is a Senior IEEE Member.

Dave Hawkins is the Manager of Special Projects Engineering in the Operations Division at the California Independent System Operator (California ISO). He joined California ISO at its startup in August of 1997 and is very involved in the operations side of this new entity. His responsibilities include assessment of new technologies, analysis of operating issues, and management of their R&D program. He is also responsible for review of industry policies and standards, and compliance with those standards. Mr. Hawkins has more than 35 years of experience in the utility industry from Con Edison in NYC, PG&E in California, EPRI and California ISO. He has served on many professional and industry committees and is currently a member of the WECC Performance Work Group. He is a Member of the IEEE, a graduate from the University of Michigan in Electrical Engineering and a graduate of Kalamazoo College with a degree in Physics.

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