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COUPLING WIND GENERATORS WITH DEFERRABLE LOADS

Project Description

Global Context of Project Idea

It is a well known fact that wind power has undergone massive growth during the last 20 years, to the point that large scale integration of wind in power systems is technically and economically conceivable. Owing to the unpredictability and variability of wind power supply, the major obstacle to wind integration is of operational rather than engineering nature.

That said, power market deregulation opens a door to a virgin territory for wind. Contrary to extraordinary technological and regulatory advancements in the supply of electricity, end-use has remained unchanged over the past hundred years: passive and inefficient. Matching electricity demand to the supply of wind power could effectively mitigate wind power randomness and variability (see figure 1). This project focuses on investigating this possibility and developing the necessary architecture to achieve this coupling within the context of existing power markets, grid operations and technological infrastructure.

The nature of the problem

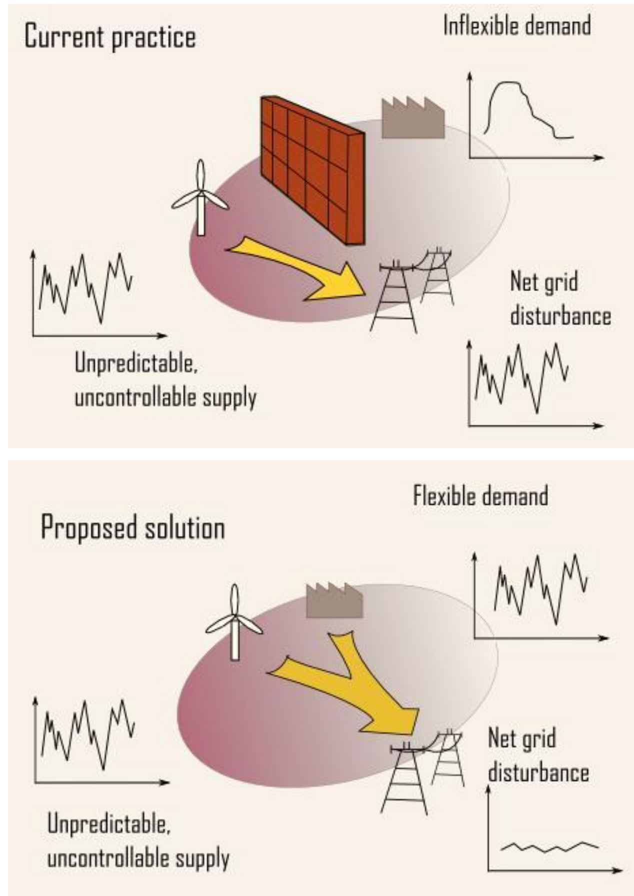
The main obstacles to large scale wind integration originate from the following two characteristics of wind power supply:

- **Randomness:** The supply of wind power cannot be forecast accurately.
- **Variability:** *Even if perfect wind forecasts were available,* wind would be a problematic power source because it varies beyond human control.

Below is a listing of resulting grid operations. For further description of power system operations refer to appendix A.

- **Hour-ahead re-dispatch:** System operators optimize the dispatch of generators days and hours in advance. The unpredictability of wind power supply may cause imbalances to the system which require expensive deviations from dispatch schedules. Starting up units to compensate for a sudden shortage in wind power supply may take hours, lead to additional air pollution, result in wear and the need for frequent maintenance of startup units, and upset system dispatch due to the minimum generation capacity of startup units.

Figure 1: Deferrable loads can provide valuable flexibility to wind generators, and given this flexibility wind generators can provide abundant cheap power. However, wind suppliers and consumers are currently detached.



Similar problems are caused by shutting down units to balance an unanticipated increase in wind power supply.

- **Primary control, secondary control and ramping requirements:** The minute-by-minute variability of wind may also cause system imbalances. This variability imposes a requirement for primary control, generators which can rapidly adjust their power output in response to an unanticipated event. Moreover, secondary control units are necessary which can back up and dismiss primary control units. The inability to perfectly forecast wind exacerbates this problem. Since wind also tends to vary rapidly and in great magnitude, an additional backup of ramping generators is necessary.

- **Positive correlation with hydropower, negative correlation with load:** Various power systems absorb large amounts of hydroelectric power. During the months that snow melts and hydroelectric power supply increases and must be absorbed, the additional generation of wind energy causes an over-supply problem. It is also possible that winds increase during the night and abate during daytime, hence wind generation is negatively correlated with electricity consumption.

- **Intermittency at high wind speeds:** Wind generators shut down for mechanical protection when winds become very strong. Since wind generators supply a significant amount of power to a system during periods of high winds, there is an increased risk of substantial supply shortage during storms. This problem is exacerbated in large wind parks operating generators with identical cutoff speeds.

The effects of the problem

- **Costs:** The costs associated with wind power integration result from the offset of variability by standby generators effect and the requirement for investments on system backup. These costs are captured by market tariffs and may be allocated to the whole market or directly to wind generators, depending on market regulations. Research and experience indicate that integration costs range between 0 and 7 $/MWh (Ackermann, 2005), (Hirst & Hild, 2004). Table 1 includes representative results for various levels of integration.

Table 1: Integration costs for various markets.

Market	Cost ($/MWh)	Integration (%)
CA PIRP*	4.3	2.4
UK	5.9 6.9	10 20
Nordic Region	1.5 3	10 20

Source: (CAISO, 2006), (Hulle, 2005)
* PIRP: Participating Intermittent Resources Program

- **Discarded power:** Wind energy may be discarded during hours of excess wind power supply if power systems cannot reliably absorb this supply (Ackermann, 2005), (Hulle, 2005). During early spring the California system operator either spills water supplies from hydroelectric dams or discards wind power (Hawkins & Loutan, 2007). Wind power is also discarded under normal operating conditions in California whenever forecasting underestimates the amount of wind power supply to the system and the excess power cannot be sold. In Texas the system operator discards wind power during load pick-up for reliability reasons.

- **Limits on large scale integration:** Though the integration of wind is increasing, an integration level beyond 20% is not perceived as economical (integration levels count 20% in Denmark, 9% in Spain, 7% in Germany, and California is aiming for 20% by 2020). Assuming capital costs for wind power will continue to decline in the future, the major challenge for the large scale integration of wind will be its variability. Currently wind generators operate under favorable regulations in many markets. A number of system operators in Europe (Denmark, Greece) and the United States (PJM, NYISO, CAISO, Ontario IMO) accept wind generation on a priority basis (DeMeo, 2004). This preferential treatment has its limitations. Large scale wind integration cannot rely on regulatory support alone, but will also require demand-side innovations.

Proposed solution

This proposal builds upon the fact that a significant proportion of the energy we consume is dedicated to duties which can be postponed. This flexibility creates a great opportunity for wind. In order to avoid the disturbances associated with the variability of wind power, wind generators can control flexible loads remotely and supply power within a not completely predictable yet reasonable amount of time. This process can be integrated to existing grid and power market operations, and it can be achieved using existing infrastructure.

The communication network between wind plants and loads is presented in figure 2. Consumers program tasks to be completed within a certain deadline and duties aggregating from different loads are scheduled according to the availability of wind power. Since load flexibility leads to significant cost savings, wind generators can offer electricity to loads at a discounted price to compensate for flexibility.

The desired result of the proposed implementation is the zero net impact on the power grid. What makes this possible are the two degrees of freedom for wind generators: load flexibility and spot market participation. Wind generators satisfy load requests upon availability of wind. If generators risk not meeting schedules they can in advance (after the load has been scheduled, but before due time) purchase power from the spot market without disturbing grid operations. In case of excess wind, generators can also sell in the spot market.

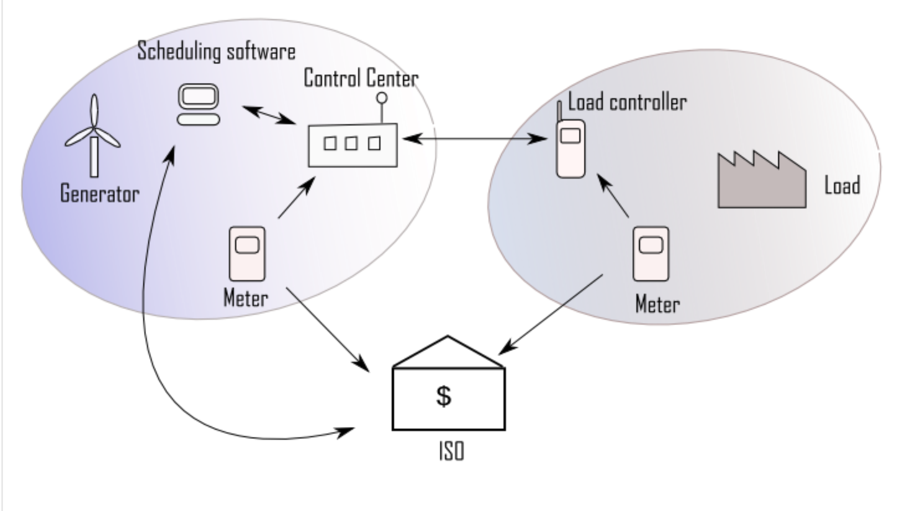


Figure 2: Data flow for proposed implementation

Technical details

- **Communication and data processing devices: Meters** are installed at every load site and at the wind power plant. The meters monitor the output of wind power and the power consumption of each load. This information is reported to the ISO and to the power plant control center at each trading interval of the spot market. The **scheduling software** uses all available data (metered data, spot market prices, load demand, weather forecasts) in order to optimally schedule the allocation of available wind power for satisfying incoming duties. Bids in the hour-ahead market can also be made automatically by the scheduling software. The **control center** acts as the interface between the scheduling software and the generator-load network. The control center collects metered and load demand data and feeds it to the scheduling algorithm. After the algorithm has determined which loads can consume power in the following interval, the control center communicates these instructions to each load controller. **Load controllers** are installed at each load site. These devices collect metered and power demand data, communicate this information to the control center and switch loads.

- **Integration with market operations:** Under the proposed implementation transactions among wind plants and deferrable loads can be conducted by a single scheduling coordinator (i.e. trader). Trades can be scheduled or even automatically conducted by the scheduling software. Bids are required for both wind plants and loads during every trading period, but upon settlement of the market the scheduling coordinator will receive the payment for the generated wind power *net the power consumed by loads*. Since the wind-load network is financially liable only for the net bid quantity, wind plants are hedged from wind variability. Additional charges may apply in case of transmission line congestion or deviations from bid quantity (e.g. in the case of bad wind forecasting). The CAISO settles this deviation mainly with two payments, the uninstructed energy payment and the uninstructed deviation penalty. Both payments are described in appendix B. Nevertheless, wind generators and flexible loads are decoupled to a significant extent from market operations.

In case the forecast wind power supply exceeds the aggregate demand of flexible loads, the excess wind can be sold in the spot market by bidding a positive net quantity. Similarly, if aggregate demand is in excess of wind power supply and wind suppliers risk missing load deadlines, the short position can be covered in the spot market in advance by bidding a negative net quantity. Hence, the wind-load network does not interfere with power system operations since wind power shortage can be settled in advance in the market rather than real time through primary and secondary control.

Load control: Load controllers (energy management systems) come in great varieties and are absolutely affordable. Hunt Technologies, Powerit, Enernoc and other companies which

Table 2: Potential deferrable loads and associated processes.

Machinery	Power rating	Applications
Industrial boilers	1.5 MW – 60 MW	Hot water services, steam generators
Electric heaters	2 kW – 1.5 MW	Water/floor/space heating for commercial buildings
Ventilators, fans, blowers	0.1 kW – 16 kW	Factories, warehouses, shopping malls, sports malls, office buildings
Air conditioning	8 kW/m^2 – 18 kW/ m^2	Office/commercial buildings
Pumps	0.1 kW – 1 MW	Irrigation, sewage, water supply, petrochemical/chemical plants
Compressors	2.5 kW – 1 MW	Refineries, chemical/petrochemical plants, natural gas processing plants
Mixers, agitators	10 kW – 1 MW	Mining, mineral processing, pulp and paper, chemical
Refrigerators	1 kW – 1 MW	Laboratories, restaurants, hospitals

Source: (Mobley, 2001), Internet

market load control technologies install load control systems for load centers as large as 50 MW at a cost of no more than $ 20,000 per installation.

- **Potential loads:** Various large scale industrial and commercial processes which are conceivably deferrable are listed in table 2.

- **Scheduling:** The complexity of the scheduling decisions can become a serious consideration for a large number of deferrable loads. Scheduling algorithms will be required to terminate within minutes, as necessitated by the rate at which the real time electricity market clears and other useful information such as weather forecasts and load requests become available. The algorithms will need to be robust to various problem parameters such as wind variability, number of loads served, load flexibility, load arrival times, power rating, service time, seasonal variations and spot price variability. Thus far, we have experimented with the earliest deadline first (EDF) algorithm. The next step will be to consider dynamic programming algorithms and adaptive stochastic controllers.

Accomplishments

- **Prototype scheduling software, simulation platform:** We have implemented an algorithm for scheduling loads and simultaneously participating in the spot market. In order to test the performance of the algorithm we have created a simple model of plant-load networks and market operations. The performance of the scheduling software has been tested in this simulation platform. The assumptions which were employed for the simulations are explained in appendix C.

The results of a representative simulation run are presented in figure 3. This simulation is run for a case of large scale integration: 10,000 MW of nominal wind capacity.

In order to attract flexible loads wind plants discount electricity at 85% of the spot price (lower left figure). Nevertheless, profit margins remain high (upper right) because variability-related costs are successfully managed by the scheduling software. To appreciate the potential of the proposal, fixed costs[1] for onshore wind are currently estimated at $40/MWh to $64/MWh (Hulle, 2005), while the total cost of power from gas-fired plants is estimated at $48/MWh to $58/MWh if costs associated with CO_2 emissions are accounted for (Hulle, 2005). Assuming that fixed costs for wind power will continue to decline and fuel costs will continue to rise, utilizing demand flexibility to keep variability charges at or below the simulation level of $7/MWh makes it plausible for wind power to **compete** against gas-fired generators for the flexible loads market. If it is reasonable to assume that approximately 15% of industrial and commercial consumption in California is flexible, this translates to an annual market potential of 30 million MWh only in California and significant environmental benefits.

[1] Note that variable costs for wind power other than the ones addressed in this project are negligible.

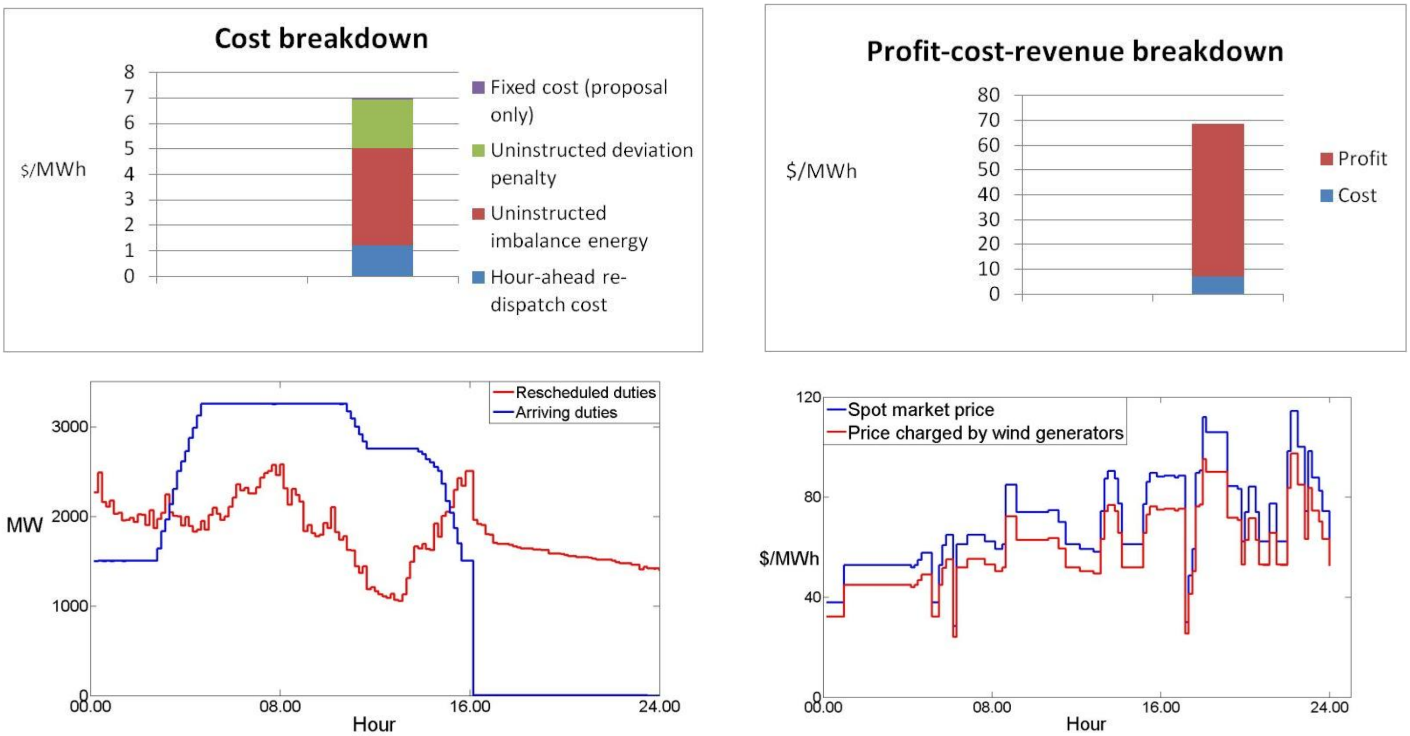


Figure 3: Preliminary simulation results suggest that the proposal can achieve competitive costs even in large scale integration.

The actual performance of the scheduling algorithm is depicted in the lower right figure. The blue line describes the inflexible load curve of a group of large industrial loads which are contracted with the wind plant, and the red line describes how the scheduling software postpones their consumption in accordance to wind availability.

The simulation results are based on an implementation of the earliest deadline first algorithm, which is a computationally efficient (hence fast) limited resource allocation algorithm. As a next step we are considering more demanding approaches such as dynamic programming (Brunetto & Tina, 2004). However, these algorithms can easily exceed time constraints due to computational complexity. Hence, we are also considering the possibility of hybrid algorithms which solve the backbone of the problem with dynamic programming and attack the remaining problem with 'softer' algorithms.

- **Clean Technology Innovation Prize semi-finalist:** This project was the basis of a proposal for the Clean Technology Innovation Prize, organized by the Center for Entrepreneurship and Technology at UC Berkeley. The proposal reached the semi-finals of the competition[2]. Though the proposal did not win any monetary prizes, we were able to gain valuable feedback from industry experts regarding potential commercial applications of the proposal.

Extensions and impact

Certain refinements to the proposal which are considered include the incorporation of transmission constraints, the optimal discounting of electricity for deferrable loads and the incorporation of constraints on machinery switching. Moreover, we hope to secure seed funding to develop a commercial product which integrates the scheduling software, the data processing platform and the communications system which is required for the implementation of the proposal. The diversity of the research team aims at tackling this interdisciplinary challenge.

The proposal integrates well with storage technology. Moreover, it applies readily to solar power which is also a source of variable and random nature. Another area of interest is the integration of solar power and geographically distant wind generators with uncorrelated output as a single market entity contracted with multiple flexible loads. Moreover, the proposed infrastructure can integrate with demand residential or commercial demand response systems. The idea of connecting 'smart' meters and 'smart'

[2] http://earth2tech.com/2008/04/08/lets-get-ready-to-rumble-cleantech-competition/.

sensors in houses with 'smart' controllers in wind plants is especially appealing.

Demand response, time-of-use pricing and interruptible service contracts target shortage supply for a few hours each year and yield the gains of demand flexibility for this limited time interval. In contrast, this proposal addresses renewable energy integration and leads to added value for intermittent generators year-round. This contrast highlights the fact that flexible loads are especially valuable for wind generators. The most ambitious goal of this project is to demonstrate that load flexibility is **valuable enough to enable large scale integration of wind power in power systems without operational disturbances**. We envision a power system where wind generators compete without subsidization or preferential treatment for the variety of consumption processes which are deferrable (figure 4).

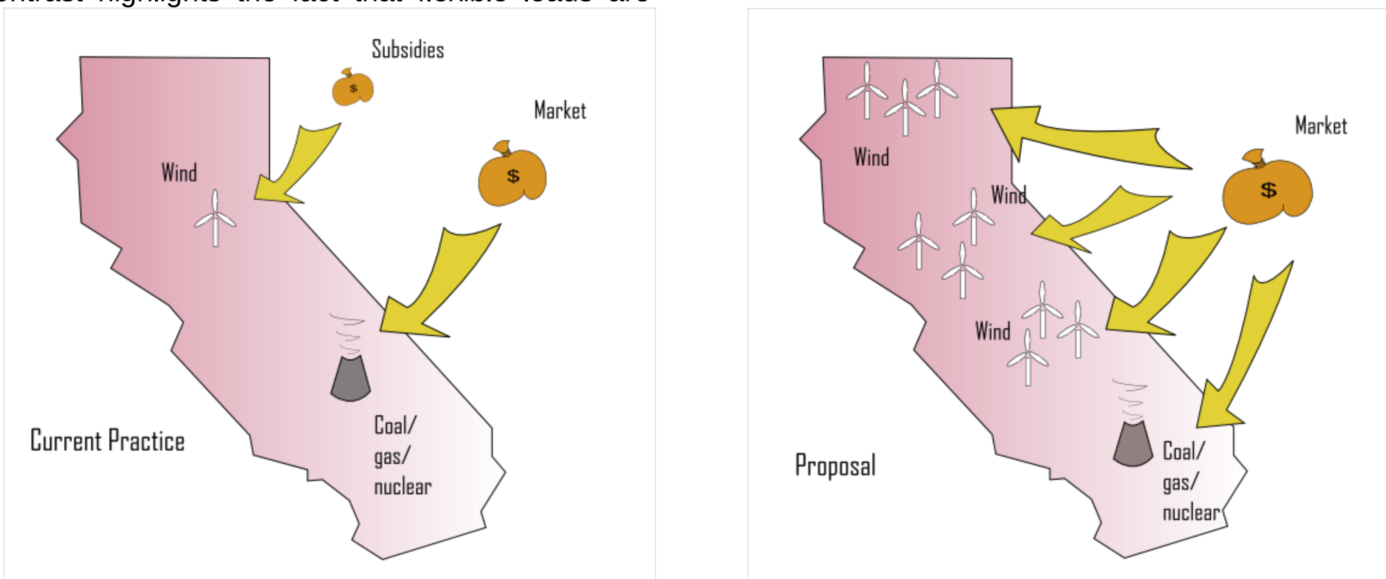


Figure 4: Renewable generators can increase sales by coupling their supply with consumers who are willing to be paid for shifting their demand. This could enhance the profitability of wind generators and the utilization of wind power.

Bios

Anthony Papavasiliou is a second year PhD student in the department of Industrial Engineering and Operations Research at UC Berkeley. His research advisor is Professor Shmuel Oren and his work is focused on power systems economics and operations. Anthony holds an undergraduate degree in Electrical Engineering from the National Technical University of Athens, Greece. Anthony will have the opportunity to further the research on this project during his summer internship at Palo Alto Research Center (former XEROX) in the context of energy management in data centers.

Shmuel Oren is Professor of Industrial Engineering and Operations Research at the University of California, Berkeley. He is the Berkeley site director of PSERC. He has published numerous articles on aspects of electricity market design and has been a consultant to various private and government organizations including the Brazilian regulatory commission, the Alberta Utility Board, the Public Utility Commission, the Polish system operator and the Public Utility Commission of Texas. He holds a BSc. and MSc. In Mechanical Engineering and Material Engineering from the Technion in Israel and he received a M.S. and PhD. in Engineering Economic Systems in 1972 from Stafnford. Dr. Oren is a fellow of INFORMS, and a fellow of the IEEE.

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Thomas Dickhoff is a first year MBA student at the Haas School of Business. He holds an undergraduate degree in Commercial Information Technology from the University of Cooperative Education in Mannheim, Germany. Before starting his MBA, Thomas worked as a self-employed management consultant, and also gained five years of consulting experience at Accenture during his career.

Budget justification

Funding for the project would be dedicated towards commercializing the idea. In particular, the money would be used to hire a technical team to assist with implementing the integrated data processing and scheduling software platform. A portion of the funds might also be used for travelling expenses, for the purpose of promoting the project to renewable energy developers.

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We consent to public, online dissemination of our proposal.

Appendix

A. CAISO operations[3]

In order to exactly match the supply and demand of electricity at all times, the ISO operates numerous markets prior to the actual operating interval (CAISO, 2007)'. Each market utilizes the latest information that is available.

- **Day-ahead dispatch:** Load serving entities and power generators submit hourly bids in the day-ahead market. The day-ahead market closes at 10.00 the day before actual operation. Optimization software determines the optimal dispatch and the CAISO publishes instructions by 13.00 the same day. The result is an hourly dispatch schedule for generators with 20-minute ramps between hours.

- **Hour-ahead dispatch:** As the actual operating hour approaches, generators and loads adjust their positions to forecast errors or unanticipated events by bidding in the hour-ahead market. These bids are also settled by optimization software and the results are published by the CAISO 75 minutes before the beginning of the operating hour. Like day-ahead schedules, hour-ahead schedules are also hourly blocks with intra-hour ramps.

- **Real time dispatch (also load following or supplemental energy dispatch):** Within each operating hour CAISO continues to adjust generator operating points every 5 minutes. 7.5 minutes prior to the beginning of a 5-minute operating interval CAISO uses hour-ahead generation bids and load forecasts to readjust the operating point of each generator for that interval. The prices that result from real time dispatch, also called ex-post zonal prices, are reported every 10 minutes and are averaged over two adjacent 5-minute intervals.

- **Regulation:** Every one minute the ISO adjusts the output of specific generators and/or loads based on reliability criteria. These generators and loads provide ancillary services to the system. The ancillary services market is cleared hour-ahead. The actual dispatch of regulation resources is empirical rather than economic.

[3] The appendix focuses on CAISO for the sake of clarity and without significant loss of generality. Also, California has committed to a 20% penetration of renewable and offers a good opportunity for case study.

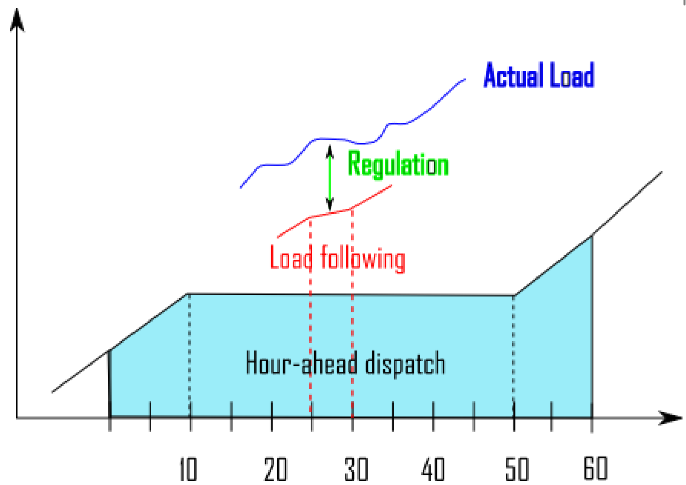

Figure 5: CAISO market timelines

B. Deviation settlement

The settlement of generator deviations from their hour-ahead schedules is settled by uninstructed imbalance energy (UIE) payments and uninstructed deviation penalties (UDP).

Uninstructed imbalance energy settlement (Bradley, 2007)**:** UIE payments are settled every 10 minutes in two tiers. The first tier is settled at a resource specific price (which depends on the ex-post zonal price) and charges generators for their deviation from dispatch instructions. The second tier is settled at the ex-post zonal price and charges generators for their deviation from hour-ahead schedules. Charges are negative (i.e. generators are paid) if generator output exceeds scheduled output.

Uninstructed deviation penalty [UDP 2007] (Borchadt, 2007)**:** UDPs are also settled every 10 minutes. These payments are intended to discourage generators from largely deviating from their schedules. A UDP is charged whenever a generator exceeds a certain deviation tolerance, defined as the greater of 5 MW and 3% of the rated capacity of the generator. For example, a 400 MW generator has a tolerance band of $\pm\max(5,0.03\cdot400) = \pm$ 12 MW from its hour-ahead schedule. If generators oversupply, the production quantity which exceeds the upper tolerance limit is charged at the ex-post zonal price. If generators undersupply, the production quantity which is short of the lower tolerance limit is charged at half the ex-post zonal price.

C. Simulation assumptions

- **Wind speed:** Wind speed is modeled by the Weibull distribution. However, the correlation between average hourly wind speeds decreases rapidly as the interval between observations increases (Hirst & Hild, 2004), which is to say that wind speed is completely unpredictable a few hours ahead. To capture both these statistical aspects of wind speed we draw independent samples from a Weibull distribution every four hours. The mean of the distribution is 8.3 m/s and the variance is 2.6 $(m/s)^2$. We interpolated samples from a Gaussian distribution to patch the holes between 4-hour periods.

- **Rating:** The available wind capacity is simulated as consisting of 10 wind parks with 500 generators each. Each generator is rated at 2 MW. The power curve of the wind plant is modeled as a cubic function of wind speed with a cut-in speed of 5 m/s which peaks at 15 m/s and cuts off at 25 m/s. In order to capture the effect of geographic dispersion among wind parks, uncorrelated wind speed data for each park were used and their output was summed to calculate aggregate wind power supply. No transmission constraints are assumed. The aggregate *nominal* wind capacity in the simulations is thus 10000 MW, which significantly exceeds the 685 MW that are operating under PIRP and the aggregate of 3500 MW in California (Loutan & Hawkins, 2007). To put these figures into perspective, the average system load of California is 27500 MW.

- **Forecasting:** Wind forecasting errors depend on how early forecasts are made. The current practice in the CAISO PIRP is that wind generators bid a quantity based on forecasts two hours ahead of actual operation. Based on CAISO studies, the forecast error for these predictions can be modeled as a truncated normal distribution with a variance of 0.0156 (Loutan & Hawkins, 2007). The same assumption is adopted in the simulation.

- **Hour-ahead re-dispatch costs:** To capture the cost that is incurred in the California system due to the fact that wind variability upsets day and hour-ahead schedules, a penalty for large variations of wind supply was introduced. These variations were charged at $30/MW, which is an approximate of the cost of rescheduling gas-fired generators to compensate for wind power (Makarov & Hawkins, 2005). These costs are not actually charged to wind generators in CAISO because wind is absorbed on a must-take basis but instead they are passed over to all market participants.

- **Loads:** 3 types of loads are used as prototypes for the simulation. These loads are modeled based on publicly available data on typical load profiles provided from Southern California Edison [SCE 2001]. The first type is large power sub-transmission (LPST) peak shaving loads rated at 200 kW with a 2 MWh energy requirement and an available time window of 14 hours. The second type is LPST intermediate loads rated at 500 kW with an energy requirement of 6 MWh and a time window of 22 hours. The third type is LPST base loads rated at 1 MW with an energy requirement of 18 MWh and a time window of 22 hours. A total of 92 loads were chosen. (SCE, 2001).

- **Capital costs:** The necessary capital costs for installing energy management systems at the load sites were based on load control technology market research. Capital costs are assumed to increase linearly from $25 to $20,000 for the range of 2.5 kW to 1 MW. The opportunity cost of the capital investment was calculated at a 5% risk free rate of return, a 10-year investment lifetime and yearly compounding.

- **Market prices:** Real time price data were recovered from the Oasis database of the CAISO web site. 10-minute ex post zonal price data were used from 02/23/2003 to 02/26/2003 for the San Francisco zone. Unfortunately, day and hour-ahead price data are not publicly available. In order to capture the risk premium of the hour-ahead market hour-ahead prices were simulated by superimposing a noisy signal with a positive bias to average ex post zonal prices.

Bibliography

Ackermann, T. (2005). *Wind Power in Power Systems.* Chichester: John Wiley & Sons.

Borchadt, T. (2007). *Uninstructed Deviation Penalty Settlements Training.* Retrieved from CAISO Settlements Training Web Site: www.caiso.com

Bradley, J. (2007). *Uninstructed Imbalance Energy Settlements Training.* Retrieved from CAISO Settlements Training Web Site: www.caiso.com/docs/2005/05/04/20050504173948574.pdf

Brunetto, C., & Tina, G. (2004, December). Optimal hydrogen storage sizing for wind power plants in day ahead electricity market. *Renewable Power Generation, IET* , pp. 220-226.

CAISO. (2007). *BPM for market operations version 5.* Retrieved from CAISO website: http://www.caiso.com/1c97/1c97c73c6c9e0ex.html

CAISO. (2006). *Settlement Charges Report for Participating Intermittent Resources Program: Calendar Year 2006.* Retrieved from CAISO Stakeholder Initiatives Web Site: http://www.caiso.com/1bee/1beec03422000.pdf

Crossley, D. (2006, November). *Low Cost Load Control Technology.* Retrieved from Library of Energy Futures Australia: www.efa.com.au/Library/LowCostLoadControlTechnology.pdf

DeMeo, E. P. (2004, December 1). *Wind Power in Electricity Markets.* Retrieved from Utility Wind Interest Group Web Site: www.uwig.org/fercwork1204/windinmarketstable.pdf

Hawkins, D., & Loutan, C. (2007, October 2). *Integration of Renewable Resources. PSERC presentation.* Retrieved from PSERC Web Site: http://www.pserc.org/cgi-pserc/getbig/generalinf/presentati/psercsemin1/pserc2007s/hawkins_pserc_tele-seminar_renewables_oct2_2007.pdf

Hirst, E., & Hild, J. (2004, April). *Integrating Large Amounts of Wind Energy with a Small Electric System.* Retrieved from http://www.ehirst.com/publications.html

Hulle, F. v. (2005). *Large Scale Integration of Wind Energy in the European Power Supply: Analysis, Recommendations and Issues.* Brussels: European Wind Energy Association.

Loutan, C., & Hawkins, D. (2007). *Integration of Renwable Resources Report: Transmission and Operating Issues and Recommendations for Integrating Renewable Resources to the CAISO Control Grid.* CAISO.

Makarov, Y., & Hawkins, D. (2005, February 3). *Wind Generation and Grid Operations: Expeirence and Perspectives.* Retrieved from CEC Web Site: http://www.energy.ca.gov/2005_energypolicy/documents/2005-02-03_workshop/2005-02-03_CORRECTED_CAISO.PDF

Mobley, K. (2001). *Plant Engineer's Handbook.* Elsevier Press.

SCE. (2001). Retrieved from SCE Web Site: http://www.sce.com/AboutSCE/Regulatory/loadprofiles/2001loadprofiles.htm