"Perfect Dispatch" – as the Measure of PJM Real Time Grid Operational Performance

Boris Gisin, Qun Gu, James V. Mitsche, Simon Tam, Hong Chen

***Abstract*—This paper discusses a novel approach for analysis of large scale real time grid operation performance. The PJM Interconnection energy market is one of the largest centralized markets in the world. Recently PJM deployed a newly developed application called "Perfect Dispatch" designed to provide a baseline measure of grid operational performance using retroactive real time market simulation and analysis. In the first nine months of 2009 over $100 million in production cost saving have been attributed to its use. This paper provides an overview of the Perfect Dispatch implementation at PJM and discusses applications and benefits of the "Perfect Dispatch".**

***Index Terms*— Energy Market, Real-time Market, economic dispatch, unit commitment, system operation**

I. Introduction

Ensuring system reliability and providing an economic efficient dispatch are the top two responsibilities of any grid operation. Thus, grid operational performance should be gauged by its compliance with these two basic objectives. However, in real-time operation reliability and economic efficiency objectives may conflict. Although most grid operators have established various performance metrics to evaluate their real-time operations, these metrics usually focus on one particular aspect, such as various reliability compliance goals, financial operating reserve usage, etc. Establishing a comprehensive performance metric that evaluates dispatch efficiency, while respecting all grid reliability constraints is a very challenging task. Such a metric would be very valuable to grid operators because it can provide the right information and incentives to achieve optimum dispatch solution.

The Perfect Dispatch (PD) idea originates from PJM Interconnection's initiative to improve real-time grid and market performance. This initiative required developing new concepts and software to derive and compare the real-time dispatch with an ideal "perfect" dispatch solution.

Various reasons could cause the actual real-time commitment and dispatch to deviate from the theoretical optimum.. Dispatchers need to work with forecasted future grid conditions, which may never materialize as expected. Dispatchers also need to operate with a certain degree of conservatism due to generation response uncertainty that cause online generation to slightly vary from online load and reserves requirements. Conservative operation necessitated by uncertainties and reliability concerns, resulting in sub-optimal commitment and dispatching actions, result in higher production cost. Variance from "perfect" can also be attributed to the real-time tools assumptions and limitations. For example, the real-time unit dispatching system (UDS) uses a limited forward optimization window, which may result in a sub-optimal solution.

The notion of the "perfect" dispatch" (PD) refers to the least production cost security-constrained dispatch and commitment solution assuming full knowledge of future conditions , and the full decision and control authority was available. Although this solution is hypothetical, a PD solution serves as a baseline for measuring actual daily grid performance and incenting more efficient operational decisions. Also, knowing the factors underlying the deviation between actual and the 'perfect' solution can be used to review real-time decisions, get recommendations for possible better commitment and dispatch actions, and guide market design thoughts.

PJM deployed the pre-production version of PD in the fall of 2007 after significant joint development efforts by PJM and PowerGEM personnel. After benchmarking and fine tuning the pre-production version for a few months, PJM developed a Perfect Dispatch goal metric. Official day-to-day operation started on April 1, 2008. Significant experience has been accumulated since then, resulting in multi-million dollar savings to PJM customers.

II. Overview of the PJM Energy Market.

The PJM Interconnection, operates a centrally dispatched, competitive wholesale electric power market that, as of December 31, 2008, had installed generating capacity over 164,000 MW and load peak of over 144,000 MW serving approximately 51 million people. PJM coordinates and directs the operation of the transmission grid and plans transmission expansion improvements.

Currently PJM operates a two settlement market system including a Day Ahead (DA) market and a Real Time (RT) market 1. Over the course of the day, PJM employs many sophisticated software applications that address various market operation aspects. Over the last 10-20 years significant improvements and new methods have been developed to

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improve PJM grid dispatching, but the means to measure the overall RT market efficiency somewhat lagged.

PJM applications related to the PD application takes place in several phases using a variety of calculations and processes, most prominently the DA, RAC (Reliability Assessment Commitment), and RT applications:

The PJM DA market is a forward market with posting time 4:p.m. for the following market day. The DA market clearing sets the commitment and the dispatch to satisfy all the financial bids, including fixed demand, price sensitive demand, virtual bids and transaction bids. The DA operating reserve requirement is also observed through a co-optimization process. Note that the DA market is a financial market in the sense that unit commitment is made to balance the financial bids rather than actual load forecast. DA virtual bidding may have significant impact on the outcome of unit commitment, dispatch, and locational marginal prices (LMPs), and provides convergence of RT and DA prices. It is important to recognize that this process clears 90-95% of the PJM market, and defines the majority of the daily unit commitment. While the DA commitment and dispatch are financially binding, additional units may be committed after DA market closing. Most of slower start units (e.g. large steam driven units) cannot be committed in RT due to notification time/start up time constraints.

Reliability Assessment Commitment (RAC) execution starts after 6 p.m. to ensure sufficient unit availability for the next operating day based on the load forecast. Several follow-up calculations, including intra-day RAC, may be performed to respond to changes in system conditions and forecasts. In the RAC period (6:00 p.m. to 12:00 a.m.), the unit commitment calculation uses the actual load forecast to access and ensure that sufficient generation capacity will be on-line to meet the real-time operation needs. PJM may commit additional slow startup units during this period if the RAC process identifies the reliability need. The commitment decision for slow startup units finalized by RAC are normally respected in the real-time operations. DA Combustion Turbine (CT)/Diesel commitments have only financial implications; the physical commitment decision of those units will be determined during the real-time operation.

Going into real-time operations, PJM primarily utilizes an automatic real-time Unit Dispatch System (UDS) executed consecutively every five minutes to optimally determine the resource commitment and dispatch. While the UDS system will constantly consider all dispatchable units to meet the real-time load and economically alleviate real-time congestion, the real-time version of UDS system uses a relatively short look-ahead horizon. PJM also executes a Look Ahead version of the UDS system with two-hour solution window, which guides quick startup unit commitment.

Operators can manually intervene in situations where the economic response of generation resource is insufficient. Interventions can be performed through the UDS system, for example, by adjusting the constraint controlling margin; or, it can happen outside the UDS system, for example, by manually calling up CTs and manually dispatching steam units.

III. The Perfect Dispatch Overview

The objective of the Perfect Dispatch (PD) solution is to identify the system commitment and dispatch that minimizes the total system bid production cost and provides optimal N-1 security-constrained unit commitment and dispatch, assuming that all system conditions would be known in advance.

Given that future conditions cannot be perfectly predicted, the perfect dispatch solution cannot be achieved in actual real-time operations. However, while being hypothetical and not fully achievable in reality, the PD solution is useful as a baseline for actual grid performance measurement, particularly:

- Measuring the performance and efficiency of RT grid operations from a market point of view on the systematic daily basis;
- Identifying the cause of the “imperfectness” and quantify the cost of such imperfectness via real time performance metrics;
- Providing recommendations to PJM dispatching staff about what changes (mainly in unit commitment) could be made during the previous day that would improve grid performance.
- Diagnosing where the market rules, short term commitment and dispatch scheduling procedures and software could be improved;

PD uses a 24 hour solution time window similar to the DA and RAC forward calculations as oppose to the limited forward solution time used by real-time unit dispatch system. This allows PD to identify a more efficient dispatch and commitment pattern.

Unlike the hourly DA and RAC calculations, PD can better capture inter-hour dynamics using a 30, 20 or 15 minute time steps, simultaneously solving the 24 hour period (48, 72 or 96 time intervals respectively). Experiments demonstrated that a yet smaller time step (10 minutes or less) did not provide significant solution benefits but suffered computationally from “real-time system noise”.

There is a very clear difference between other PJM market applications that address projected looking forward grid conditions, dispatch and commitment, and the Perfect Dispatch. For example, DA market applications start with “blank” hourly load flow models. Generation and load dispatch are completely determined by the DA SCUC and SCED. Accounting for the impact of the external control areas is limited to modeling predicted uncontrollable loop flows. PD is examining the system in retrospect from known conditions.

PD is a “look back” application that performs “re-optimization” in retrospect starting from the actual real-time PJM grid dispatch. PD can be executed only after the closing of the actual RT market day [Figure 1**Error! Reference source not found.**]. The goal of PD is to identify possible performance improvements based on the incremental “re-optimization” of the RT grid operation performance.

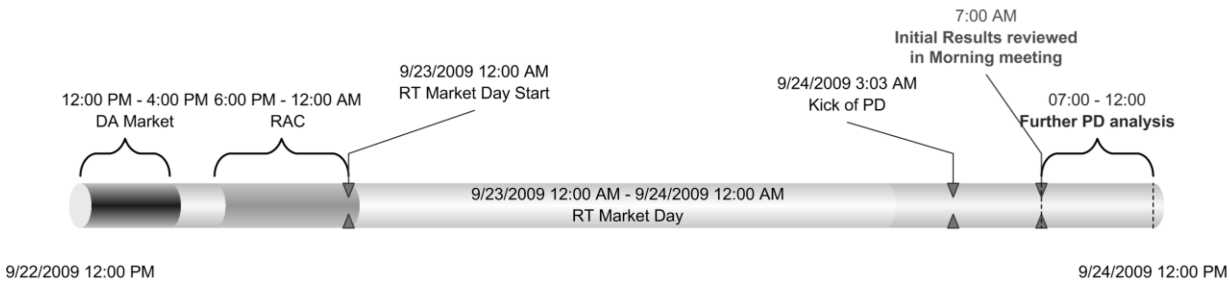

Figure 1 PJM market application timeline

PD is designed to respect the real-time operational reality as much as possible. For example, the PD user can limit eligible units for real-time unit commitment changes based on their characteristics, such as startup, notification time, or minimum run time to reflect real-time operational reality.

PD focuses on the reoptimization of only those generators that can potentially be redispatched and recommitted in real-time. Many factors defining actual real-time system conditions are modeled that cannot be adjusted during the PD simulation. Examples of unchangeable real time factors are grid topology, generation and load dispatch of external control areas, internal PJM load, self-scheduled generators, and generators not optimized in the real-time market (typically nuclear, hydro and wind). PD captures these factors by using a models built from actual Energy Management System (EMS) State Estimator snapshots with many external areas beyond PJM itself.

IV. PD REAL TIME DATA

Conceptually, all the PD input data can be categorized into two groups, load flow model related data and market data. In general, market data are indexed by pricing nodes (Pnodes) and/or bid identifications, while load flow data are identified by the EMS equipment name. The linkage between market node (identified by Pnode) and the physical node (identified by Enode) is provided by a one-to-multiple mapping relationship between the two. Figure 2 summarizes the major types of PD data and the LF to market data link between the two.

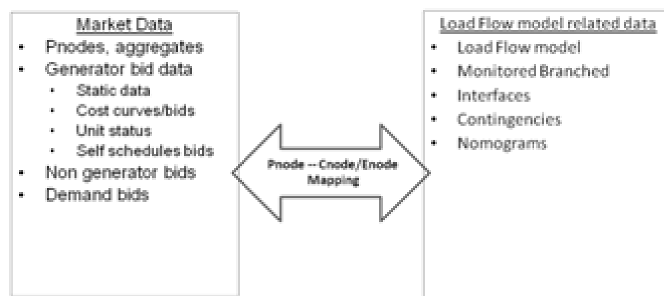

Figure 2 PD input data

Each EMS LF snapshot model is assumed to have different grid topology that cannot be changed during PD simulations. PD simultaneously manages from 24 to 96 load flow models assuming that each snapshot may have a different grid topology, number of buses, and generator shift factors. Complementing the network data, PD also links and manages a large amount of market and generator dispatch data. These include generator bids, day-ahead and real-time unit status, real-time unit output and dispatching signals, and unit commitment characteristics.

PJM developed a new process for the PD implementation imbedded into the current PJM EMS that saves solved state estimator snapshots every five minutes as a separate load flow case file. These models were expanded to include additional mapping data providing market data mapping to physical resources modeled in real-time snapshots. Such mapping is critical to connect the physical and aggregate market bid data that will be re-optimized during the PD solution.

PJM has been accumulating real-time data at five minute intervals (288 per day) since August 2007, each saved snapshot representing approximately 15,000 buses, The daily data set requires close to two GB of disk space without compression. The PD simulation can reconstruct and rerun from any of these saved market days. This capability has proven to be very valuable for analyzing historical grid performance, and as a database feeding many other PJM analyses unrelated to PD.

PD input data come from a variety of sources, including EMS state estimator, day-ahead market, real-time UDS and real-time LMP software and databases. Each of these applications run on different computer systems at different frequencies. For example, the EMS state estimator is executed every minute, the real-time UDS runs every few minutes; and the real-time LMP calculator runs every five minutes. An important consideration in the PD input data design is to appropriately align data from these different sources. Using the five minutes RT LMP calculator snapshots as the baseline to align data from other RT/EMS applications proved to provide the most consistent environment and data mapping for the PD calculations.

V. Modeling Details

The Perfect Dispatch calculation data from real time operation is either fixed and unchanging in the simulation, or is under PJM control and can be optimized/adjusted by PD.
The vast majority of PD data is fixed data and is comprised of:

- All external control areas generation dispatch, load, area interchanges,
- The majority of PJM internal grid data including grid topology, load MW, MW output for generators not under PJM dispatch, and various local controls statuses.

In contrast with the day-ahead clearing, which performs an unit commitment and dispatch from "scratch", PD performs an incremental security constrained unit commitment and dispatch from an initial real-time state. This approach ensures that the non-dispatchable parameters, such as interchanges, loop flow and the output of self dispatching units are preserved as actually occurred in RT.

The primary optimized parameters in PD are the status and output of dispatchable generators generally based on their bid-in characteristics. When generator recorded performance is different than bid-in characteristics, PD adjusts the bid-in characteristics to match the recordings. For example, from time to time units may violate bid-in minimum or maximum MW output. During such instances, PD will adjust these data to align with real-time dispatch. As another example, PD modifies unit ramping characteristics if a unit demonstrated different capabilities in real-time.

Like any security constrained unit commitment algorithm, the Perfect Dispatch solution objective is to identify the optimal generating unit operating status and dispatch that does not cause any overload under normal pre-contingency or n-1 contingency conditions. To produce realistic changes to the recorded dispatch, PD limits generator control to only those under direct PJM control during this dispatch period. Depending on the type of the analysis being performed, the user selects various generator types for optimization. Typically the types are:

1. Fixed commitment and dispatch generators.
2. Generators that can be redispatched but not committed or decommitted by PD .
3. Generators that can be committed for additional hours (typically extending the previous commitment), but not de-committed.
4. Generators that can start and stop within a day.

In general, nuclear, hydro and pump storage units are not dispatchable in real-time. Thus, they fall into the category of 'Fixed commitment and dispatch generators'. Other self-scheduled generators also fall into this category. Usually the commitment status of dispatchable steam units is not changed during real-time operation, but dispatch can change within the dispatchable range, categorizing them as type 2 or 3 depending on the study objective. Typically PD has the most commitment selection capability with quick start units such as GT's and diesels that are available for action during the real time period.

A. *Out of merit generator RT bid production cost (BPC)*

In RT operations, most units generally closely follow their dispatch signals, but unavoidable variances often occur. Sometimes this difference can be significant, particularly when transmission congestion is a deciding factor. For example, a unit may bid 200 MW on a price curve of $40, and up to 250 MW at $500. This unit may continue operating at output more than 200 MW even if the real-time LMP is in the $60 range, irrespective of the UDS signal dispatching it down. In this situation PD will redispatch the unit down in contrast to the recorded reality. Under such circumstances using the original bid curve will lead to an over-estimation of BPC saving. If the original bid curve is the BPC cost basis, the saving is based on $440/ MW-Hr ($500-$60). This 'saving' is un-realistic because it cannot be achieved by improving PJM's operation. In this case, PD adjusts the unit cost curve to that of the real-time LMP. The logic is: if the market participant consistently volunteers to be operating within $500/MW segment, being paid the clearing real-time LMP (in this example, $60), the $60 LMP indicates the true market participant incremental cost.

B. *Ancillary services*

Currently the PJM ancillary market optimization is performed in the hour ahead reserve allocation, not in real time. Therefore, since PD analysis is limited to an examination of the real time period, it currently does not perform any ancillary market re-optimization. PD enforces the ancillary services market as given by optimizing dispatchable generators within their range. This approach may be reconsidered in the near future.

C. *Constraints modeling*

To produce results with acceptable speed, PD uses a flowgate-based (interfaces and monitored element – contingency pairs) constraint modeling approach for about 4,000+ flowgate simultaneously enforced flow constraints. To ensure that this constraint set does not overlook any constraint violation in changing hour-by-hour network and dispatch conditions, PD monitors four groups of constraints:

- All active UDS constraints that has been active (not necessary binding) in UDS for at least one hourly interval.
- Any constraint that has been active during a pre-set long time window, for example 180 days.
- All reactive interface constraints regardless whether they are active or not. These constraints represent the static voltage stability transfer capability between areas of the system.
- Coordinated PJM/MISO market-to-market flowgates.

VI. PD Implementation platform

The PJM PD implementation is based on the SCUC implementation within the PowerGEM PROBE software 2. Initially the PROBE software was developed as an economic analysis tool to assist with the long term transmission planning and provide economic justification for the various transmission expansion projects and retirements using DA market data. In 2004 PROBE was placed into daily production as a DA decision support tool. Currently primarily PROBE applications for DA clearance include:

- Refined unit commitment precisely accounting for all N-1 transmission constrains
- Pump storage multi-period optimization
- DA mitigation based on accepted FERC approved three pivotal suppliers test
- Quick sensitivity study tool for use during the daily noon to 4:00 p.m. DA clearing time window

Several years of daily production use of PROBE for DA decision support has provided numerous benefits, including:

- Significant improvement in the consistency between the day-ahead unit commitment, LMP, and dispatch,
- Reduction in day-ahead reserve uplift payments (“make unit whole”),
- Facilitated on-time day-ahead market clearing every day,
- Improved day-ahead market clearance transparency from PROBE reporting.

PJM also uses PROBE for other applications as well, including:

- PJM transmission outage review and market information
- Reliability Assessment Commitment
- Market monitoring and mitigation
- Market performance and compliance reporting
- Financial Transmission Right (FTR) adequacy analysis and FTR market support

Building on this extensive experience base and its modeling speed and granularity PROBE was selected as the natural choice for the PD implementation.

The centerpiece of the PROBE software are state of the art security constraint unit commitment (SCUC) and security constrained economic dispatch (SCED) algorithms. The PROBE solution engine is based on the several integrated components including:

- Iterative linear (DC) load flow accounting for losses and N-1 contingency analysis. A good review of various DC load flow technique can be found in reference 3
- LP based full SCED utilizing dual simplex similar to the methods first introduced in 4. An incremental SCED customized and tuned to the power system analysis problem structure was developed. Extremely fast “hot start” SCED runs are combined with an intelligent dynamic programming / mixed integer search approach to quickly and reliably arrive at the least production cost unit commitment. To correctly optimize pump storage and energy limited resources, PROBE solves 24 hours within a single simultaneous solution.

Currently PD utilizes a sequential forward single period SCED solution consistent with the current PJM real-time practice, leading to 24 hour unit commitment and dispatch solutions in one to two minutes. The more comprehensive full day (24 time periods) day-ahead calculation clears 5,000 to 10,000 bidders per hour solution time, requiring between five and ten minutes solution time utilizing a single PC CPU.

VII. PD Applications and studies

A. *BPC Savings metric*

The major PJM PD use is to provide a benchmarking metric of real-time operational efficiency. While it is never expected that the bid production cost (BPC) could be reduced to the perfect condition, consistent measurement and reduction of the actual versus perfect production cost can provide a signpost towards more efficient operations. PJM has established a corporate metric based on the PD solution for real time operation since April, 2008. This metric measures the gap between the real-time BPC value and the BPC value of the ‘perfect’ solution and derives a “percentage of perfect” score.

$$POP\ Score = 1 - \left(\frac{BPC_{RT} - BPC_{PD}}{BPC_{PD}}\right) \qquad (1)$$

BPC_{PD} is the BPC cost of the optimal solution found by the PD application, while BPC_{RT} is the BPC cost as actually occurred in real-time. If any transmission constraint violation occur either on the real-time or PD side, BPC penalties based on UDS shadow price may be applied when congestion cannot be resolved.

Figure 3 shows the PD produced “percent of perfect” metric for January through September 2009. For the 2008 baseline period, the average BPC score was 98.18 percent. PJM’s target of 2009 is to improve the average performance by 10 percentage points; that is to a PD score of 98.37 percent. The ??? line indicates the year to date running average PD score. Any unusual deviation from the normal variance can indicate a “bad day” which prompts a daily or more detailed investigation as to root causes and lessons learned.

As it can be seen, the operation efficiency has been improving over the course of the year, at least partially due to the information and feedback from the PD process.

In practice, the “percent of perfect” metric calculation in (1) involves engineering judgment and managerial understanding. Various PD settings and solution options yield a different PD solution that reflect the reality of system operations with greater or diminished clarity, but for consistency these choices are made once per year for a particular PD application. For example, PJM chooses to use the generator type optimization modes as indicated in [Figure 3] and a 30-minute simulation time step.

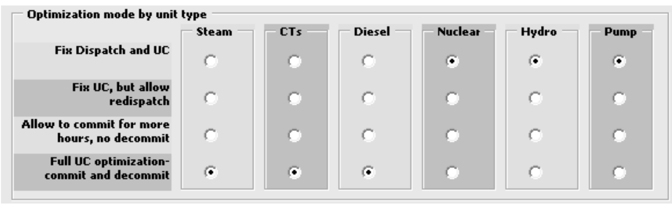

Figure 3 Generator optimization mode settings

Comparing human operator commitment decisions with that of PD may reveal whether decisions in the event were appropriate, and whether a more effective or cost efficient alternative was available.

For example, on June 2, 2009 the real-time operator called on 16 CTs for transmission constraint control, where the Perfect Dispatch solution suggested using only three, costing $1.3 million less. The PD alternative used longer minimum run time, slower starting units that have lower total daily cost when a longer, multi-hour view was taken. Understandably, an operator will tend towards using faster starting but more expensive units in times of uncertainty. The next time such a situation is encountered operators may be able to consider the previous PD alternative to make reliable lower cost decisions.

As another example, the commitment decisions in a broader corporate and process context, the commitment “handed” to the real-time operators from the preceding RAC commitment can be reviewed in retrospect. The RAC commitment of large, slow moving steam units may be consistent with economical reliability preservation, but may turn out to be not as economical comparing to the use of fast start units in real time. The PD retrospective review is used to study where RAC improvements and refinements may have a positive effect.

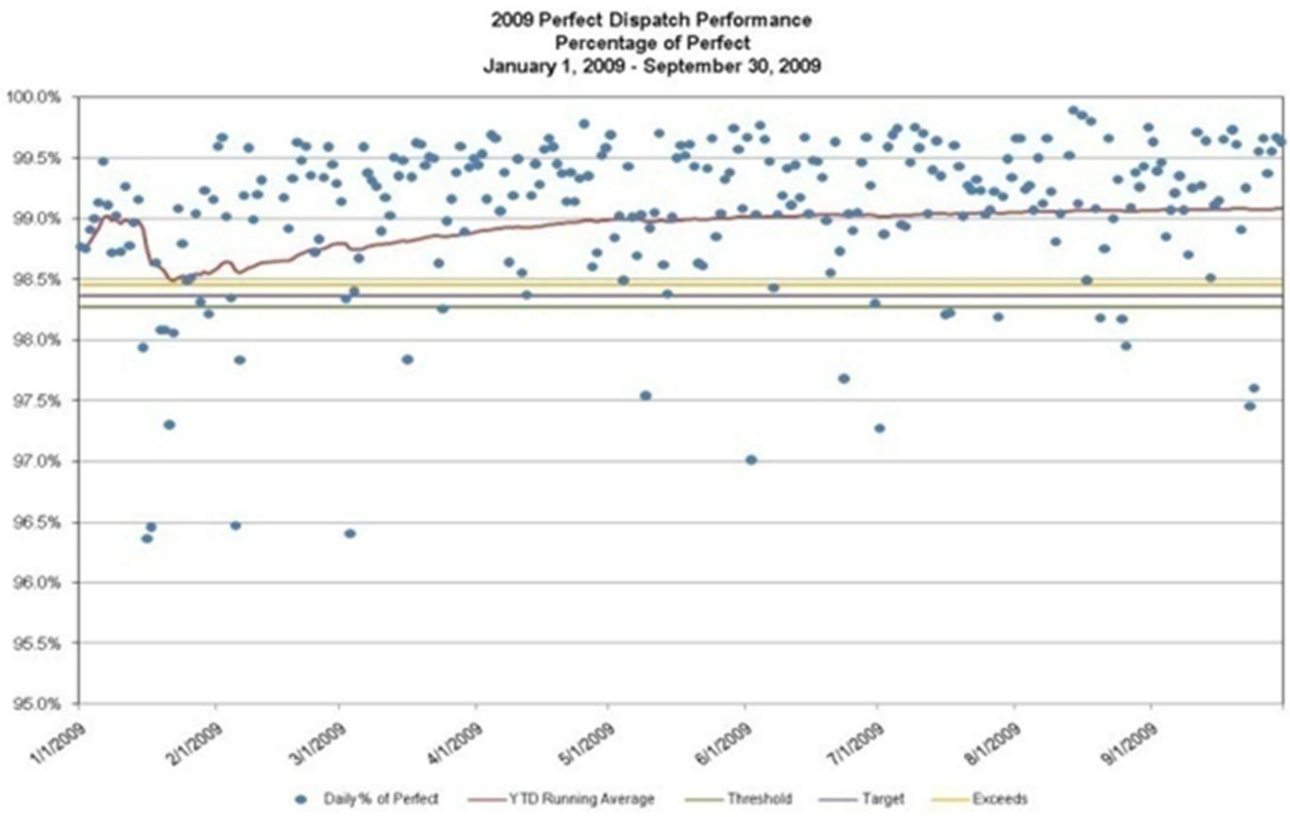

Figure 4 2009 January – September 2009 production Cost Saving Metrics

B. Commitment Improvements

Real-time operators are under pressure to make quick decisions in a fast changing environment, involving billions of dollars, with eyes on preserving grid reliability at the same time. The practical feedback and improvement suggestions from PD post-operational analysis and results are useful for sharpening operator decision making, and as an operator training tool.

C. Individual unit performance sensitivity analysis

In real-time operation, PJM’s UDS provides a consistent dispatch signal to all committed units. While a majority of the units follow these signals reasonably well, some do not, ramping much slower than bid-in ramp rate, or do not respond at all. Poor performance of such units has negative impact on the total system cost. Prior to PD implementation, PJM had no means of quantifying the impact of such units.

Quantifying the impact of the poorly performing units begins by establishing the unit dispatch pattern and resulting production cost if units respond perfectly with a PD retrospective. Then, a series of 'what if' simulations are executed for each study unit to assess its contribution to the 'imperfectness'. During 'what if' runs, the PD tool either fixes the study unit's dispatch as occurred in real-time or derates the study unit ramp rate based on its real-time performance. Such a study requires numerous incremental PD SCUC simulations, further emphasizing the need for fast calculations.

The results and implications for market and enforcement improvements are compelling enough to justify this expenditure of development and analysis resources. An actual individual unit performance review performed for the June 2009 operating period yielded the "top ten" worst performing unit list shown in the table below.

Based on this analysis individual units were contacted for an explanation of their real-time performance. An updating of a unit minimum operating point data significantly improved one unit's subsequent performance.

D. Intra-day PD runs

A normal PD optimization is carried out on the full 24-hour window. However, the need has arisen to study dispatching actions and possibilities during a specific period at real-time, for instance during the morning load pick up period, or during temporary maintenance that induced high congestion. For such occasions, PD can start at any time of day and perform a partial day optimization. In a sense, PD can be used as a multi-period unit dispatching study tool apart from its usual retrospective focus.

E. Demand Response Analysis

In addition to its performance review role, PD can be used as a market design and refinement tool to review rule or process changes impact using historic data to test their effectiveness, and to avoid unintended negative consequences by running a series of PD "what if" studies.

Demand response market structure development is a prominent example where PD analysis is being used for market design. Recently, the benefits of the demand response resources (DSRs) are receiving more and more attention by independent system operator (ISO) market stakeholders, policy makers, and market designers. PJM encourages and has experienced increased participation in these programs. Currently there are three basic types of DSRs in the PJM market: (1) economic based dispatchable DSR, (2) self-scheduled DSR and (3) reliability based load curtailment. The DA market only considers the first DSR type, while all three types are available in the real-time market. PD provides a tool to analyze how these various DSR types can be integrated into the whole market clearing process to the total customer benefit.

Two PROBE PD executions are required to evaluate the operational DSR impact:

- A baseline simulation is performed with DSR dispatch fixed as occurred in real-time.
- In the second run, additional "DSR bids" are modeled as optimized parameters

Comparing these two PD runs quantifies the impact of DSR bids and reports the critical BPC impact, LMP change, and fuel usage shift of these new market resources.

F. RT Transmission Limit Control

PJM selectively uses dynamic transmission ratings on active binding constraints and interfaces. Quantifying the financial benefit of these actions was not possible prior to the PD implementation.

Unit	Number of unit operating days	Monthly Production Cost Impact	Perfect Dispatch Average Daily Saving
1	**14**	**$192,660**	**$13,761**
2	**30**	**$144,027**	**$4,801**
3	**24**	**$136,559**	**$5,690**
4	**27**	**$119,972**	**$4,443**
5	**29**	**$118,424**	**$4,084**
6	**30**	**$111,173**	**$3,706**
7	**24**	**$110,533**	**$4,606**
8	**24**	**$91,543**	**$3,814**
9	**30**	**$83,194**	**$2,773**
10	**29**	**$77,270**	**$2,664**

By using PD BPC impact analysis, PJM was able to further tune and improve real-time ratings management, increasing contingency conditions equipment utilization from 97% to 100% starting from Feb. 1, 2009 (i.e. reducing uncertainty ratings safety margins) 5.

VIII. PJM BENEFITS SUMMARY

Consistent daily analysis of PD recommendations to effect procedural and operator training changes at PJM since April 2008 has been a significant success, as measured by production cost saving. From January to September 2009, PJM estimated an annual saving of $101 million from PD 6. This saving is achieved from increased awareness and diligence to the most cost efficient dispatching options, and process improvements discovered through detailed daily PD analysis.

Most of the reported saving can be attributed to the improved unit commitment of the quick start units. Further savings may be realized with continuing and more advanced use of the Perfect Dispatch.

IX. Conclusion

Establishing a transparent and objective performance metric to evaluate electricity market operational efficiency is an important but challenging task. The Perfect Dispatch adaptation of the PROBE software is designed specifically to address this challenge. The Perfect Dispatch tool can accurately model real-time market rules and operational constraints, providing an informative and insightful retrospective view of operating decisions. In addition to providing an objective performance metric, PD can provide insight into potential data and dispatching improvement opportunities, and act as a powerful market design tool.

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