Performance Evaluation System for Power Grid Dispatch and Operation

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***Abstract*--In this paper, a new performance evaluation system used for large scale power grid operation is presented. It can not only be used to provide system dispatch baseline assessment, but also to quantitatively evaluate the influence from different kinds of impact factors. The evaluation system uses the mature Security Constrained Unit Commitment / Security Constrained Economic Dispatch (SCUC/SCED) model, which has been successfully applied in many RTO/ISOs in North America, as the basis of optimization engine. By analyzing large number of important historical data gathered during the running of the grid, it objectively evaluates and analyzes the grid operation of the previous day(s) to find out the possible economic and security problems. The analysis focuses on the various aspects of the differences between the actual system operational results and the optimal dispatch proposed by the optimization engine. Resolutions will be provided to improve the efficiency of system dispatch and operation. The evaluation system was installed in NCG (North China Grid) dispatch center and was put into operation in 2010. The effectiveness of the system has been proven through more than one year's NCG operation practice.**

***Index Terms*—After Fact Analysis, Economic Dispatch, Economic Metrics, Impact Factor, Performance Evaluation, Unit Commitment**

I. Introduction

As a major utility supplying the capital region electricity demand, the North China Grid (NCG) has seen, amid the rapid development of Chinese economy, the strong needs to enhance its scheduling/dispatch business processes with advanced and innovative technology. In 2007, NCG established a comprehensive generation scheduling system covering time windows from year-to-month, month-to-day contract decomposition to Day-Ahead (DA) generation scheduling. In 2008, the system was expanded to Intra-day time frame with two scheduling cycles: Big Loop (BL) to cover longer term Look-Ahead (LA) (6-8 hours) study and Small Loop (SL) to cover 1-2 hour Look-Ahead (LA) study. A Comprehensive Operating Plan (COP) was also implemented to realize the coordination between DA and Intra-Day scheduling processes. From 2009 to 2010, NCG further upgraded its scheduling/dispatch system with the state-of-the-art GCA (Generation Control Applications) engine to easily accommodate any required scheduling process cross different time frames with seamless coordination between them.

With the increasingly closer ties between NCG and other regional power grids, the trans-regional transmission capacity continues to increase, which brings more pressure on the grid operation and makes the system dispatch more difficult. In recent years, some problems, such as the poor coordination of the frequency control and tie-line schedule, the untimely system dispatching instruction and executions, the out-of-date reserve and loss apportionment policies and the imperfect network security mechanism, are growingly apparent [1]. Therefore, introducing advanced evaluation technologies to analyze the existing issues on system dispatch and operation becomes the key of today's NCG to ensure a secure grid and reliable power supply.

The introduction of the Performance Evaluation System is a major project for NCG to improve the quality of its system dispatch and operation. The evaluation system uses the mature Security Constrained Unit Commitment / Security Constrained Economic Dispatch (SCUC/SCED) model, which has been successfully applied in many RTO/ISOs in North America, as the core optimization engine. By analyzing large number of important historical data gathered during the running of the grid, it objectively evaluates and analyzes the grid operation of the previous day(s) to find out the possible economic and security problems. The analysis focuses on the various aspects of the differences between the actual system operational results and the optimal dispatch proposed by the optimization engine. Resolutions will be proposed to improve the dispatching and market efficiency and to realize the optimization of grid security and economy.

In this paper, this After Fact Analysis (AFA) based performance evaluation system aforementioned is introduced from different aspects: system overview and architectural design; the historical data collection and reference case creation, the application of impact factors, etc. The benefits of the system which have been proven by practical operation are also included.

II. System Design Overview

As mentioned in the previous section, the new power grid operation performance evaluation system is an AFA based product for systematic analysis of past events and practices. It is used to establish quantitative assessments of how specific events and practices affect grid performance. A key characteristic of AFA is the use of actual system operational

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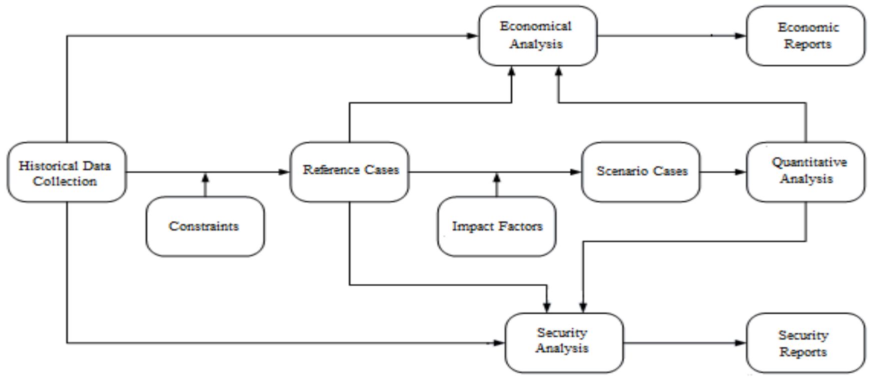


Fig. 1 The overview diagram of the AFA evaluation system

data, which helps establish a suitable level of credibility and practicality of the AFA analytical results. The business objectives of this evaluation system include:

- Assessing the performance of system dispatch by comparing economic performance metrics for actual system dispatch with those for the reference case and/or scenario cases.
- Analyzing economic performance impacts associated with certain specific operating events.

Fig. 1 shows the overview diagram of this AFA based performance evaluation system. For a specific study day, the evaluation system collects the necessary historical data, and runs the state-of-the-art optimization engine, DSPD, (Dynamic Scheduling, Pricing & Dispatch, the SCUC/SCED engine) to construct an ideal reference case that represents the optimal solution of the day. After that, a set of scenario cases can be created by applying different kinds of impact factors and executed to study the impacts on the day's operation performance caused by the input data variations. Then, related economic metrics will be calculated to evaluate the system performance quantitatively.

Specifically, this AFA based study is solely based on the approved small loop cases of the study day. There will be 96 (15-minute) intervals in the study, and the optimization engine (DSPD) will do a time coupling run for all the 96 intervals. At the end of a study, as an option, SFT (Simultaneous Feasibility Test, a simplified contingency analysis module) Check can be executed to perform the security check for the study solution. An operator can analyze the SFT Check results and decide whether a watch-list constraint needs to be included in future study.

Within an AFA study, according to the system operation performance evaluation standard, unit recommitment may be allowed for a certain set of units. However, the study will be much faster if no unit recommitment is allowed.

A reporting tool will also be provided so that the performance evaluation reports can be produced. Additionally, real time contingency analysis results (i.e., violation list) will be also available so that the data can be used by the downstream security performance analysis. The NCG dynamic limit function [2] is also supported.

III. The Creation and Use of Reference Case

One of the most important functions of the performance evaluation system is the creation of a reasonable reference case which represents the optimal solution of the study day. The performance evaluation is realized based on the comparison of corresponding data obtained from this optimal solution and those collected from actual system operation. Generally, the following real time historical data for each 15-minute interval from State Estimator (SE) need to be collected for the AFA evaluation study:

- Actual internal (NCG) area load (MW)
- Actual internal (NCG) area loss (MW)
- Actual net interchange between the internal (NCG) area and other external areas (MW)
- Actual online/offline status for units in the internal (NCG) area
- Actual MW outputs for online units in the internal (NCG) area
- State Estimator savecase (data snapshot for a particular study interval, including topology data, reactive power data, loss sensitivity, etc.)
- AGC units in the internal (NCG) area

The AFA reference case can be created on a user friendly interface (Fig. 2) and configured to use the following input data:

- Actual load
- Actual unit commitment or unit recommitment allowed
- Actual network topology
- Actual unit MW for units on fixed MW schedule
- Unit nominal capacity (high & low limits) and ramp rate
- Watch list (WL) constraints enforced during the day
- Regulation and spinning reserve results of the small loop cases, which originally come from Day-Ahead (DA) solution. For the current phase, NCG does not do co-optimization unit ancillary service when it solves for the unit commitment and dispatch. Thus PD needs to use the ancillary service results originally provided by DA.

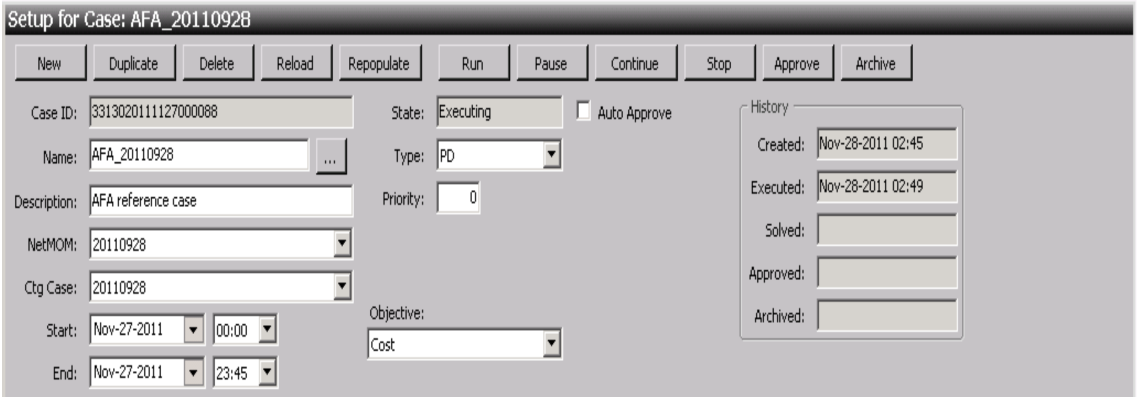


Fig. 2 Create and execute of reference case on user interface

Once the reference case is created, the performance evaluation system will use the optimization engine to perform the re-analysis to the 96 study intervals throughout the day. Various objective functions can be selected to satisfy the system performance evaluation requirement. The following objective functions are supported in the present evaluation system:

- Minimize the total operating cost
- Minimize the total power purchasing cost (based on the NCG network electricity prices)
- Minimize the total fuel consumption
- Minimize the controllable network loss

The unit schedule from the reference case solution can be tested by SFT and the testing results will be used to determine whether a watch-list constraint needs to be included in future study.

As mentioned earlier, the solution of the reference case will be considered as the “best” (e.g., lowest cost) dispatch result that is “theoretically” possible. Using the comparison tool provided by the evaluation system, the differences between this ideal operation status and the actual operation status are generated and further quantitative analysis can be performed to analyze the factors that lead to the differences. Fig.3 shows the illustration of system production cost difference between the reference case solution and the actual operation status. The comparison of different quantitative criterion is shown in Fig. 4.

As shown in Fig. 4, the quantitative comparison between the reference case and the actual operation status can be realized in the system, plant or unit level. This multi-level comparison mechanism significantly simplifies the process to figure out the reason which causes the criterion difference.

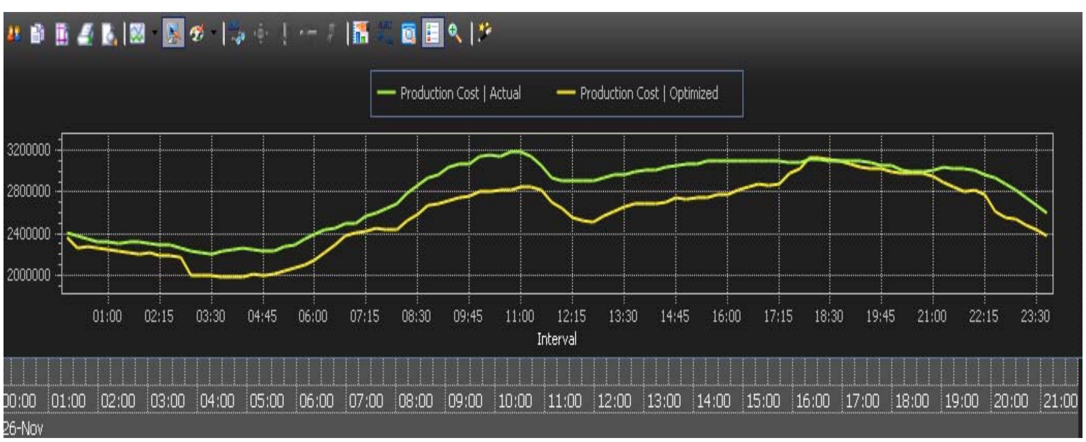
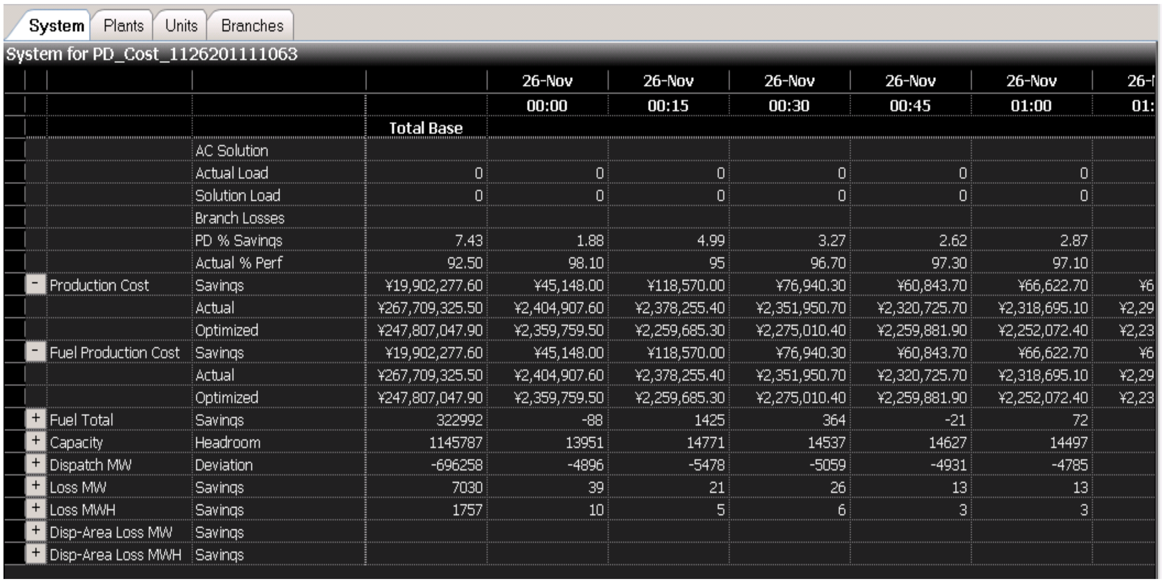


Fig. 3 The illustration of system production cost difference between reference case and actual operation status



System Plants Units Branches

System for PD_Cost_1126201111063

			26-Nov	26-Nov	26-Nov	26-Nov	26-Nov	26-I
			00:00	00:15	00:30	00:45	01:00	01:
		Total Base						
	AC Solution							
	Actual Load	0	0	0	0	0	0	
	Solution Load	0	0	0	0	0	0	
	Branch Losses							
	PD % Savings	7.43	1.88	4.99	3.27	2.62	2.87	
	Actual % Perf	92.50	98.10	95	96.70	97.30	97.10	
Production Cost	Savings	¥19,902,277.60	¥45,148.00	¥118,570.00	¥76,940.30	¥60,843.70	¥66,622.70	¥6
	Actual	¥267,709,325.50	¥2,404,907.60	¥2,378,255.40	¥2,351,950.70	¥2,320,725.70	¥2,318,695.10	¥2,29
	Optimized	¥247,807,047.90	¥2,359,759.50	¥2,259,685.30	¥2,275,010.40	¥2,259,881.90	¥2,252,072.40	¥2,23
Fuel Production Cost	Savings	¥19,902,277.60	¥45,148.00	¥118,570.00	¥76,940.30	¥60,843.70	¥66,622.70	¥6
	Actual	¥267,709,325.50	¥2,404,907.60	¥2,378,255.40	¥2,351,950.70	¥2,320,725.70	¥2,318,695.10	¥2,29
	Optimized	¥247,807,047.90	¥2,359,759.50	¥2,259,685.30	¥2,275,010.40	¥2,259,881.90	¥2,252,072.40	¥2,23
Fuel Total	Savings	322992	-88	1425	364	-21	72	
Capacity	Headroom	1145787	13951	14771	14537	14627	14497	
Dispatch MW	Deviation	-696258	-4896	-5478	-5059	-4931	-4785	
Loss MW	Savings	7030	39	21	26	13	13	
Loss MWH	Savings	1757	10	5	6	3	3	
Disp-Area Loss MW	Savings							
Disp-Area Loss MWH	Savings							

Fig. 4 The quantitative criterion comparison between reference case and actual operation status

IV. Scenario Cases and Impact Factors

Impact factor is an input to the performance evaluation system that can be adjusted to allow the evaluation mechanism to study its impact on the performance metrics. Scenario cases are the results of applying impact factors (i.e., changing of the input data) to the reference case, which are used to study the effects of those impact factors to the system, such as, how much additional cost a particular impact factor would cause.

The following impact factors are supported in the present performance evaluation system:

- Internal (NCG) area load change (to show the effects of load forecast error)
- Tie line schedule change between the internal (NCG) area and other external areas
- Unit dispatch limits (economic max / min) and ramp rate
- Unit fixed MW schedule
- Unit commitment status (specifying must-run, must-off, and recommitment allowed periods)
- Constraints enforced status and upper/lower limits
- Network topology (e.g., specifying equipments' out-of-service periods)

The scenario cases can be created on user interface. Multiple scenario cases can be created at the same time by applying different impact factor(s) respectively.

Once the scenario cases are all available, the performance evaluation system will use the optimization engine to run all the related scenario cases in batch mode. The difference between a scenario case and its corresponding reference case is caused by applying the impact factor(s). The scenario case solving process can also be configured to use actual unit commitment or unit recommitment allowed. But the objective function has to be the same as the selected for the reference case. Based on the analysis requirement, one or more scenario cases can be excluded from a specific batch run to facilitate the case storage and the performance evaluation process.

Taking advantage of the comparison tool mentioned in section III, the differences between scenario cases and their corresponding reference case can be analyzed to evaluate the effects of those impact factors to the system operation. The column "Total D1" in Fig. 5 shows the quantitative criterion difference between scenario case 1 and its reference case. Again, the comparison can be realized in different levels (system, plant or unit) to facilitate the further analysis.

V. Economic Metrics Calculation

The evaluation system uses the economic metrics to quantitatively assess the grid operation performance and the economic metrics are also an important tool to help system analyzer to figure out what leads to operation performance deterioration. In present performance evaluation system, following economic metrics will be calculated and presented on user interface for NCG internal area:

- Total actual production cost (¥)
- Average actual production cost (¥/MWH)
- Total AFA production cost (¥)
- Average AFA production cost (¥/MWH)
- PD percentage saving

  100(actual production cost – AFA production cost) / (AFA production cost) %* (1)
- Actual percentage performance

  (100 – PD percentage saving) % (2)

System | Plants | Units | Branches

System for PD_Cost_1126201111063_1_01

					26-Nov			
					00:00			
		Total Base	Total C1	Total D1	Base	C1	D1	Ba
	AC Solution							
	Actual Load	0	0	0	0	0	0	
	Solution Load	0	0	0	0	0	0	
	Branch Losses			0			0	
	PD % Savings	8.95	7.43	-1.51	3.42	1.88	-1.55	
	Actual % Perf	91	92.50	1.50	96.50	98.10	1.50	
- Production Cost	Savings	¥24,075,758.80	¥19,902,277.60	-¥4,173,481.20	¥82,904.10	¥45,148.00	-¥37,756.10	¥15
	Actual	¥269,151,715.70	¥267,709,325.50	-¥1,442,390.10	¥2,420,918.70	¥2,404,907.60	-¥16,011.10	¥2,39
	Optimized	¥245,075,956.80	¥247,807,047.90	¥2,731,091.00	¥2,338,014.50	¥2,359,759.50	¥21,745.00	¥2,24
- Fuel Production Cost	Savings	¥24,075,758.80	¥19,902,277.60	-¥4,173,481.20	¥82,904.10	¥45,148.00	-¥37,756.10	¥15
	Actual	¥269,151,715.70	¥267,709,325.50	-¥1,442,390.10	¥2,420,918.70	¥2,404,907.60	-¥16,011.10	¥2,39
	Optimized	¥245,075,956.80	¥247,807,047.90	¥2,731,091.00	¥2,338,014.50	¥2,359,759.50	¥21,745.00	¥2,24
+ Fuel Total	Savings	418090	322992	-95098	761	-88	-848	
+ Capacity	Headroom	1169813	1145787	-24026	14145	13951	-194	
+ Dispatch MW	Deviation	-720286	-696258	24027	-5090	-4896	194	
+ Loss MW	Savings	7277	7030	-247	49	39	-10	
+ Loss MWH	Savings	1819	1757	-62	12	10	-2	
+ Disp-Area Loss MW	Savings			0			0	
+ Disp-Area Loss MWH	Savings			0			0	

Fig. 5 The quantitative criterion comparison between scenario case and its corresponding reference case

VI. Benefits of AFA evaluation system

The AFA performance evaluation system was installed in NCG dispatch center and was put into use in 2010. Benefits from this evaluation system have been proven through more than one year's operation. Different from the major power grids in North America [3], most of the generation resources in NCG are fuel units with really long startup and shutdown time. The total capacity of fast units is limited. Relatively, the dispatch and operation flexibility of NCG is less than that of its North America partners. Also, until now, the market competition mechanism has not been fully established in China. System dispatch and operation are strongly confined by the interference of administrative policies. System operators usually dispatch the system mainly based on their personal experiences. The use of AFA power grid operation performance evaluation system provides NCG an opportunity to find out the existing problem in its existing dispatch mechanism and take measures to improve its operation efficiency. Three examples are given as follows:

Case 1: Insufficient regulation reserve due to operator's override

In spring 2011, due to the strong wind in North China region, in the couple hours after the midnight, most wind farm units reached their maximum economic output. But the system load demand was in the valley period. To accept the cheaper renewable generation as much as possible, the operators had to lower the output of other fuel units. In several successive operating days, insufficient downward regulation reserve was reported by NCG operators. It seems that the obvious solution to this problem is to curtail the wind farm generation. AFA analysis figured out that the problem was not fully caused by the unacceptable renewable generation, but partially caused by the inappropriate override of some major generators' minimum operation limits. This discovery effectively alleviated the insufficient regulation reserve problem.

Case 2: Strange reference case solution due to poor tie line schedule data

In 2011, NCG analyzer reported several strange AFA reference cases with higher total production cost than the corresponding actual operation cost. Detailed historical data analysis showed that, in many study intervals, the actual system generation, load and tie line interchange are not in balance. For some intervals, the imbalanced value may be as large as hundreds of MW. Further analysis found out that the problem came from the poor tie line schedule data. Based on this analysis, NCG are focusing on how to improve the quality of their tie line schedule data, because this problem definitely will bring impact on the system dispatch efficiency.

Case 3: Limited network loss reduction due to plant energy contract constraint

In China, the purchase/sell prices of electricity are controlled by government and therefore the transmission network loss reduction is an effective way to bring benefits to NCG. Based on their operational experiences, NCG operators applied different kinds of measures but none of them reduce the network losses effectively. Finally, it was through AFA analysis that helped to figure out the cause was the strong plant energy contract (signed between NCG and some major generating plants to guarantee their total annual generating capacity) that restricts the optimization results.

VII. Conclusion

In this paper, a new power grid dispatch and operation performance evaluation system installed in NCG is introduced in detail. By creating a reasonable reference case, the evaluation system represents an optimal solution of the study day. A strong and flexible comparison tool provides the capability to compare the optimal solution to the actual operation status and other scenario case solutions. The differences discovered can be used for further detailed analysis to determine the reasons that may affect the system operation performance. The effectiveness of the new evaluation system has been proven through more than one year's NCG operation practice.

VIII. References

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IX. Biographies

Ming Jin (M'10, SM'10) received his B.Sc. E and M. Sc. E from Shanghai Jiao Tong University, China, and Ph.D. from the University of Western Ontario, Canada. Now he is working with ALSTOM Grid and is responsible to design, implement and test the optimization engine for different electricity market applications.

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