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The Relationship of Primary, Secondary, and Tertiary Regulation / Dispatch under High Wind Penetration

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SUMMARY

This paper investigates the operational benefits of three different methods of providing secondary reserves in National Grid system under future higher penetration of wind generation. New automatic balancing mechanisms that will be feasible under National Grid's new Electricity Balancing System (EBS) were of particular interest to the system operators. Secondary reserve products including manual balancing operations, automatic balancing orders, and Automatic Generation Control (AGC) were evaluated using DNV GL's operational analysis simulation tools SFLEX and KERMIT as well as a new market cost model developed by National Grid. A vigorous dynamic simulation of entire power system is performed that includes inertial, governor and regulation response as well as AGC. High resolution load and wind profiles are simulated and incorporated into the model to capture the system variably in the future. The impact of relative timing and delays in various control schemes as well as their interrelationships on system frequency control have been examined. Our findings show that the new EBS reduces the urgency to implement a new secondary reserve product as manual operators using the new automation facilities of EBS are able to sufficiently control system frequency to within the limits of current National Grid standards.

KEYWORDS

Renewable Integration, Balancing Market, Economic Dispatch, Primary Response, Secondary Response, Tertiary Dispatch

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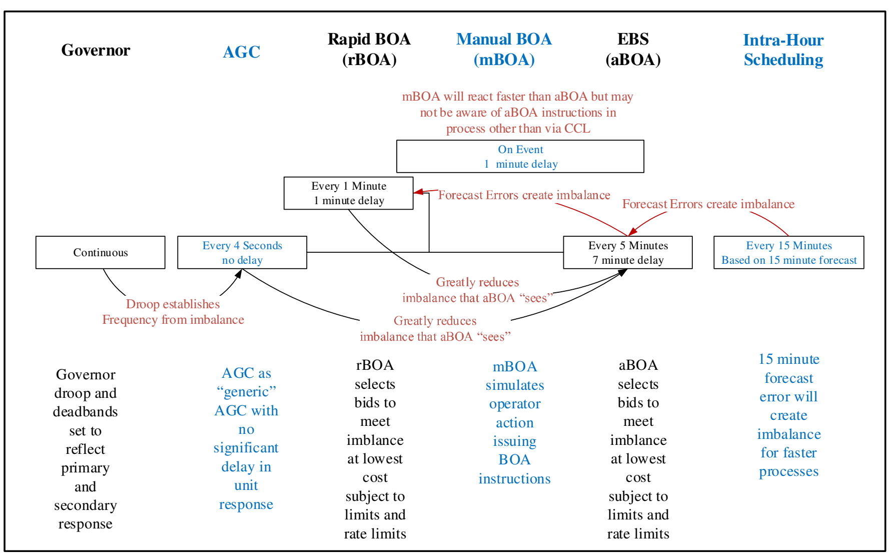
Introduction

High penetrations of renewable resources – wind and solar- introduce high levels of variability into the generation–load imbalance which must be managed by the controllable resources available to the system operator. Multiple prior studies have looked at system dynamic performance, system regulation and balancing requirements, and how to utilize fast resources such as fast storage to help manage the higher variability [1, 2, 3, and 7]. A related phenomenon is that at high levels of renewable production, fewer conventional generation units may be on-line. This decreases system inertia and primary (governor) response which can aggravate the regulation and balancing problem. DNV GL (formerly KEMA) has developed a simulation tool, KERMIT (KEMA Renewable Market Integration Tool), for studying these phenomena. This tool can be used to evaluate system performance under different scenarios of renewable penetration, operational policies for maintaining levels of conventional generation on-line, different control strategies, and so on. The particular study described in this paper is an investigation of high wind penetration in the UK system and the National Grid frequency control performance under different scenarios of the use of primary (governor), secondary (AGC), and tertiary (dispatch or in the UK lexicon Bid Offer Acceptance, "BOA"). The background is that National Grid today does not use an automated AGC but instead relies on a market product for governor response. The questions to be addressed were: 1- what would the impact of high wind penetration and higher variability on system frequency control and control room workload be; and 2- what were the relative merits of implementing AGC versus performing a real time dispatch or rapid BOA (rBOA) more frequently with tightened requirements for generating unit response to rBOA instructions.

Balancing Products in National Grid System

Figure 1[2] shows the different primary, secondary, and tertiary products, their relative timings, and interrelationships. Governor response and AGC are familiar to all control area operators; the National Grid governor response product is mandatory for all units connected to the National Grid transmission system that are greater than 100 MW and primary control (i.e., governor response) has reduced dead bands and specified droop and rate of response as compared with "normal" governor response which is reserved for large disturbances. The BOA process is automated at a 5-minute periodicity with an optimization algorithm, not unlike the balancing market operation in other market operators. The 15-minute and hour-ahead schedules are produced by a market scheduling optimization algorithm, again not unlike other market operators.



[2] CCL mentioned in the figure stands for Capped Committed Level - This is the expected output of a unit using their declared profile and modified by any BOAs already issued.

Figure 1: Primary, secondary, and tertiary products

The following sections will describe the details of overall workflow of the study including: system dynamics simulation and its calibration, future sub-hourly wind production modelling, and real time balancing dispatch modelling.

System Dynamics Simulation; KERMIT

DNV GL's proprietary simulation tool, KERMIT, was used to model the UK grid performance under the future wind scenarios. KERMIT was originally designed to study the impact of variable non-dispatchable resources on electric-power systems yet it is finding a variety of new applications [1 and 4] with grid operators across the U.S. and Europe. KERMIT allows an analysis of dynamic grid performance in future scenarios or during events such as generator trips, sudden load rejection, and volatile renewable resource (wind, solar) ramping events [5]. The software runs on a MATLAB platform and incorporates inertial, governor and regulation response as well as Automatic Generation Control (AGC). Simulations are performed one day at a time over 24 hours and model inputs typically include data on power plants such as capacity, minimum stable level, ramp rates, frequency droops and deadband, hourly and sub-hourly wind and solar production profiles, load profiles and generation and interchange hourly schedules. In this work dispatch profiles were taken from PLEXOS model, and sub-hourly load and wind profiles were simulated as described in next section. The outputs include second by second power plant's generation, area interchange and frequency deviation, real-time dispatch requirements, and numerous other dynamic variables.

KERMIT model was set up for National Grid and was calibrated against a historical trip event (see Figure 2 for calibration results). Simulated frequency response matches actual frequency nadir and recovery time within 0.01% error. Standard deviation and frequency excursions are also well matched within 10% error as shown in Figure 2.

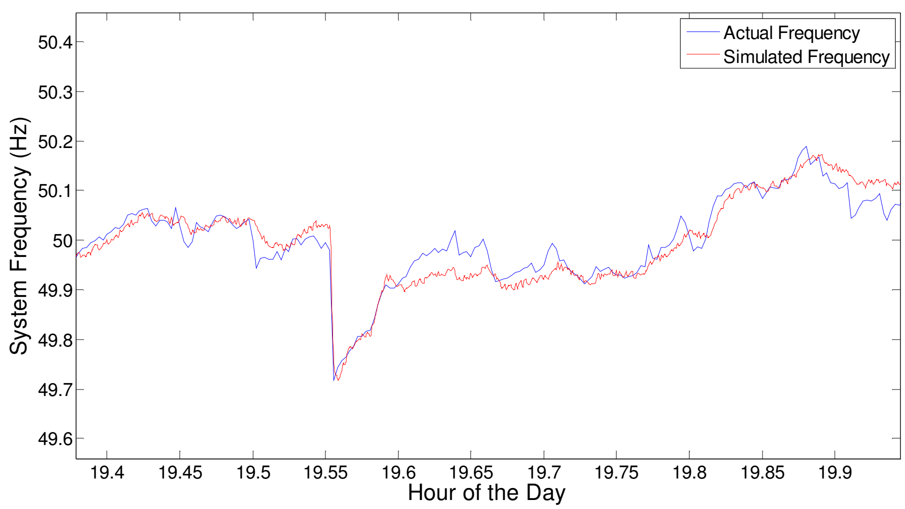


Figure 2: KERMIT Calibration

The KERMIT tool was adapted to include the BOA dispatch control which is described later on in the paper.

Challenges in performing this study beyond the normal issues of implementing a detailed model of the generating units, control systems, and power system included:

- Developing a fine grained (1-second time step) time series for wind production in the future when planned or hypothetical wind farms are in place, using limited 1-minute or slower wind data from a subset of potential future locations as the starting point.
- Simulating manual control room operations realistically
- Calibrating a complex simulation of system dynamics, control systems, and market operations to historical data and events
- Developing scenarios for future market products and product performance specifications that would expose the interplay of the different products and allow realistic exploration of the trade-offs between different holdings (procurement/utilization levels) of the various products

Sub-hourly Wind and Load Profiles

One of the inputs to KERMIT model is high resolution (e.g., 1-second) wind production data. We used our proprietary System Flexibility Analysis tool [5], SFLEX to forecast how variability changes as penetration of renewable resources grows. SFLEX is based on state of the art wind, solar and load variability models that enable accurate characterization of sub-hourly variability of power system through modelling the frequency- and time domain variability characteristics of renewable and load resources. Fourier transform techniques are used to estimate the power spectral density of wind generation and to characterize the variability of actual wind plant output. We calibrated the model using hourly and 5- minute time series of wind profiles from a subset of potential future wind farms and historical load profiles, and simulated sub-hourly time series for future scenarios. The calibration was performed through power spectral densities as well as comparison of historical and simulated data through ramp rate histograms, statistics, and sample time series plots.

Real Time Economic Dispatch

The rBOA and aBOA products were modelled as a linear programming problem based on a pre-selected set of conventional units capable of either automated or rapid response for rBOA or aBOA respectively. The assignment logic was such that units could be either on rBOA or aBOA but not on both. The optimization takes into account the plants physical characteristics such as capacity and ramp rate limits, the head room and foot room at each point in time based on simulated plant's output in KERMIT (i.e., the combination of day-ahead set points and variations around them due to governor response, AGC, and prior BOAs instructions), and units bids and offers as given by National Grid.. Both rBOA and aBOA use the same optimization formulation with different periodicity and delay parameters. rBOA is run every one minute, and has a 1-minute total delay from collecting data on frequency deviation, and units' generation levels to solving the optimization, clearing the market, and issuing instructions to participating units. The aBOA product is run every 5 minutes and has a 7-minute total delay. The solution computes the MW imbalance and solves the BOA for each assigned unit. The BOA implementation was validated by examining a range of periodicity and delay parameters. The simulation results show that 1-minute delay for rBOA is the best trade-off in terms of both performance and cost.

The manual operator (mBOA) was modelled in KERMIT as a set-point triggered dispatch where instructions are issued based on the current system frequency deviation. The implementation was developed in conjunction with National Grid to mimic their control room operations and the frequency triggers were tuned based on the operator's behavior. The dispatch of mBOA was validated using historical dispatch data.

Results and Discussions

A total of six scenarios, shown in Table 1, were modelled to represent the current and future control products. As shown in Table 1, governor response remains on throughout all of the permutations and aBOA is only turned off in order to study the effect of controlling the system frequency by just using governor/primary control. It should also be noted that aBOA can co-exist with AGC, mBOA and rBOA, but rBOA mBOA and AGC are mutually exclusive. The results presented here were considered as normal/expected wind penetration/variability based on National Grid's *Gone Green Future Energy Scenario* [8] developed in 2012.

Table 1: KERMIT Scenarios

Scenario	Governor Response	aBOA	rBOA	mBOA	AGC
1	✓				
2	✓	✓			
3	✓	✓		✓	
4	✓	✓	✓		
5	✓	✓			✓
6	✓	✓			✓

Two key performance metrics were used to evaluate the scenarios: 1- The standard deviation of the frequency deviation, is required by National Grid to be less than 0.07 Hz over 24 hours, and 2- The percentage of time the frequency deviation is outside +/- 0.2 Hz (These are pre-fault operational limits imposed to ensure that the system stays within statutory limits). In addition, a cost analysis model has been developed by National Grid to assess the cost of providing balancing products in each scenario.
Table 2 presents the annualized simulation results of 14 representative days throughout the year 2020. Two sensitivities around AGC bandwidth, namely, 300 and 600 MW were performed. The results show that Governor only and aBOA only cannot control frequency deviations such that the standard deviation stays within 0.07 Hz. As such violations beyond +/- 0.2 Hz also occur. AGC with a bandwidth of 600 MW has the tightest frequency control and no deviations from +/- 0.2 Hz when compared to lower bandwidth (300 MW). While mBOA and rBOA products, which also have aBOA active, have mostly similar performance to one another, the combination of mBOA and aBOA is the trade-off winner when the cost of these control schemes are considered. These results show that for the expected future level of variability in National Grid's system, mBOA and aBOA can sufficiently control the frequency deviations and keep the system reliability within the acceptable range.

Figure 3 illustrates how aBOA and rBOA perform given their periodicity and delay. aBOA can have adverse impact on frequency when units respond to instructions that were issued 7 minutes ago based on imbalance calculations that may have changed by the time of units' response to aBOA. Therefore, a faster product should accompany aBOA to sufficiently control the frequency.

Moreover, forecast errors or other errors in the scheduling and dispatch functions create more imbalance which will adversely impact the shorter periodicity products in immediately following time periods. Aggressive response from faster products will leave less amount of imbalance for slower products to deal with in subsequent time periods. Proper co-ordination of the different products is critical to realizing satisfactory performance.

Conclusion

The work presented in this paper investigated how various secondary reserve products including manual operators, automated balancing orders (aBOA and rapid BOA, rBOA) and AGC can effectively control system frequency in the face of higher wind productions in the future. Our simulations show that slower control schemes alone such as aBOA are not sufficient to tightly control the frequency deviations. However, manual operator actions, if tuned properly according to system conditions, combined with aBOA is able to control frequency excursions within acceptable limits, and is the most cost-effective solution alternative. Moreover, these control mechanisms should be coordinated and consider one another's control activities to avoid adverse interactions. Finally, errors in the scheduling and dispatch functions create more imbalance which will adversely impact the shorter periodicity products in immediately-following time periods. These errors and other sudden imbalance corrections from faster products will reduce the effectiveness of slower products. Therefore, proper coordination of the different products is critical to realizing satisfactory performance.

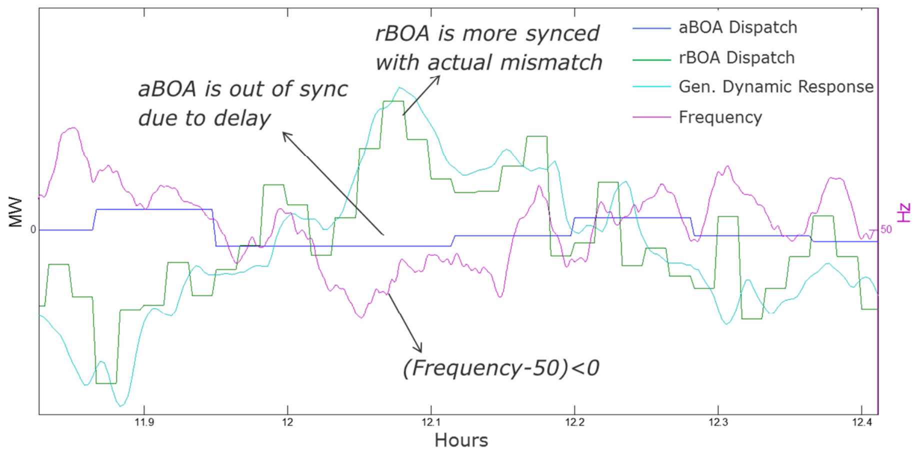


Figure 3: aBOA and rBOA dispatch, and system frequency for a sample time interval.

Table 2: KERMIT Case Study Results

Renewable Variability	ASR Product	Frequency Deviation			% Frequency Outside of +/- 0.2 HZ		
		Average Std Dev for All Days	Max Daily Std Dev	Min Daily Std Dev	Average	Max	Min
Normal Variability	Gov Only	0.0743	0.133	0.0326	4%	15%	0%
	aBOA Only	0.0719	0.1274	0.0323	3%	11%	0%
	mBOA	0.0578	0.0926	0.0314	1%	3%	0%
	rBOA	0.0578	0.0967	0.0276	0%	0%	0%
	AGC (300)	0.0578	0.0942	0.0243	1%	5%	0%
	AGC (600)	0.0416	0.0777	0.0201	0%	3%	0%

Future Work

This study raised some interesting questions which could be the subject of future work. One is to better design the interplay of the different products. For instance, it has long been the case that real time dispatch (economic dispatch, or balancing market) would include as part of the MW requirement the amount of change in generation from prior dispatch due to AGC actions. This helps maintain AGC as a near zero energy product – a capacity product and not an energy product. The same question could be asked about how the rBOA dispatch could be used to change the slower aBOA dispatch or even the future 15 minute schedules. An important question is to further investigate the performance and economic benefits of improved short term wind forecasting as results from this study and others (cite the CA ISO Advanced AGC study) demonstrate significant improvement in performance if accurate 5, 15, and 30 minute forecasts can be obtained – especially of ramping events. Another question revolves around improved market products and optimization algorithms for including storage in the balancing markets. Studies have looked at storage as a price taker in the balancing market – performing time arbitrage (cite CPUC studies and CEC studies here) but not as a new market product for short term arbitrage.

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