# Diminutive-Tenure Vigor Harmonizing Accompanied by Escalating Breeze Vigor Stratum

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***Abstract-*** Escalating stratums of breeze vigor, which is variable, difficult to predict accurately, and escalating connected via power electronic converters, are changing how electricity grids are planned, designed, and operated. . Systems with high breeze penetration are also experiencing dramatic changes to the operating regimes of conventional resources to areas with large loads. Optimal diminutive-tenure (minutes to day ahead) vigor harmonizing for systems with high breeze penetration, which is the focus here, requires high-quality breeze forecasts and advanced scheduling methodologies. These advances from the traditional scheduling approach include: dynamic reserve targets, higher resolution scheduling periods, more frequent scheduling, and the use of stochastic optimization techniques. Here, some of the possible evolutions in optimal diminutive-tenure vigor harmonizing to better deal with breeze vigor uncertainty are investigated. The focus is mainly on managing reserves through changes in scheduling, in particular market structure (more regular and higher resolution scheduling), reserve procurement (dynamic as opposed to static), and improved operational planning (stochastic as opposed to detenureinistic). Infrastructure changes including flexible plant, increased demand side participation, more interconnection, transmission, larger harmonizing areas, and critically improved forecasting can also be significant and are dealt with in the discussion. The evolutions are tightly coupled, their impact is system-dependent and so no "best" set is identifiable but experience of system operators will be critical to future developments.

***Index Terms-*** Vigor harmonizing, market design, power system operations, reserve allocation, scheduling, unit commitment, breeze power.

## I. INTRODUCTION

Escalating stratums of breeze vigor, which is variable, difficult to predict accurately, and escalating connected via power electronic converters, are changing how electricity grids are planned, designed, and operated [1]. For example, the spatially distributed, asynchronous nature of breeze vigor is driving upgrades in the transmission system, with deployment of high voltage direct current transmission (HVDC) becoming escalating popular to connect areas with good breeze resources to areas with large loads. Systems with high breeze penetration are also experiencing dramatic changes to the operating regimes of conventional generators, which must now operate more flexibly in order to accommodate variable breeze power. The displacement of conventional generation also impacts power system dynamics as the voltage support and frequency response previously supplied by these units are also displaced [2], [3]. The increased variability and uncertainty that comes with increased breeze vigor penetrations exists across multiple time scales and makes vigor harmonizing more challenging. Long tenure vigor harmonizing is complicated by the fact that the capacity value of breeze for a given system can vary significantly from year to year [4]. Optimal diminutive-tenure (minutes to day ahead) vigor harmonizing for systems with high breeze penetration, which is the focus here, requires high-quality breeze forecasts and advanced scheduling methodologies.The performance of these approaches is heavily influenced by infrastructural and portfolio changes in the power system. In particular, a more flexible portfolio, more demand side participation, increased interconnection, transmission, larger harmonizing areas, and improved breeze forecasting [5]. The remainder of the paper is arranged as follows: Section II briefly summarizes how diminutive-tenure vigor harmonizing is currently achieved through the scheduling process and how large-scale breeze vigor penetration may impact this process. Section III describes advancements to the traditional scheduling methodology that are being implemented in industry and/or proposed in the literature. Section IV discusses longer tenure infrastructural developments in the power system that will impact diminutive-tenure vigor harmonizing with escalating stratums of breeze vigor. Section V concludes

## II. DIMINUTIVE-TENURE VIGOR HARMONIZING AND BREEZE VIGOR

The primary objective of optimal diminutive-tenure vigor harmonizing is to minimize costs while maintaining the balance between supply and demand at, or above, a desired reliability stratum. The problem can be studied by modeling unit commitment (UC), which shorts the commitment schedule of units, in combination with economic dispatch (ED), which detenureines the dispatch stratum of those units in real time. UC tools commit units, typically day-ahead, based on the demand forecast and requirement for reserves and are subject to both unit

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constraints (e.g., minimum generation) and system constraints (e.g., transmission capacity). Reserves, with various activation times, ensure sufficient generation is available to meet forecast errors, contingencies, and variations over diminutives time resolutions than the resolution of the UC and dispatch (typically one hour down to 5 min). Therefore, committed units need to be able to manage primary, secondary, and tertiary frequency control as well as meet the ramp requirements over all time frames. As breeze vigor increases, the most impacted reserve categories are regulating reserves and load following reserves together with supplemental/replacement reserves (see [6] for discussion on reserve tenureinology)." If necessary, the system operator may recommit units intraday to allow for significant changes in demand or contingencies. Intraday markets perform a similar function where they exist. Demand follows daily, weekly, and seasonal patterns and as such demand forecasts are relatively accurate. Consequently, UC optimization approaches have traditionally been detenureinistic, with uncertainty in demand and power generation being accounted for by provision of reserves. Breeze power forecasts by contrast are relatively inaccurate, particularly in the day-ahead time-scale, as error increases strongly with time horizon. This can be seen in Fig. 1 which illustrates breeze power forecast error at various time horizons on the 2020 Dutch system. This study used an atmospheric model to generate breeze speed forecasts. In the diminutive-tenure (1–6 hours ahead), information from online breeze or breeze power measurements have to be used in addition to the numerical weather prediction model data to reach a good performance [9].. At low penetrations of breeze power, additional reserves can be scheduled to cover the additional uncertainty due to breeze power. However, as the breeze power penetration grows, it becomes escalating inefficient to rely on

TABLE I
Evolutions For Short-Term Energy Balancing With Increasing Wind Energy Penetrations

| Explanation | | Scheduling rate: Once per day | Scheduling rate: More regular scheduling |
|---|---|---|---|
| Dynamic assets procurement | A assets requirement that is based on dynamic forecast error estimates at different time horizons | Breeze power increases tertiary assets significantly, but the impact will be more limited when the forecast uncertainty is accounted for dynamically. | The combined impact of more regular UC and dynamic assets procurement would help to keep tertiary assets requirement relatively low most of the time. |
| Stochastic UC | Optimization of UC decisions over several scenarios for possible outcomes of breeze and demand | Improves the reliability and yields more optimal UC. | Reduces tertiary assets procurement and improves UC optimally further. |
| Scheduling resolution | Scheduling period is shorted eg from hourly to five minutes | Ramp within the scheduling period will be smaller, which reduces regulating assets. Scheduling accuracy will be improved. | |

existing methods for reserve quantification and scheduling. Section III explores evolutions to scheduling that are being studied and in some cases applied in industry

## III. Scheduling Evolutions

Table I summarizes the evolutions in the scheduling methodology that are currently being deployed and/or proposed for diminutive-tenure vigor harmonizing with high stratums of breeze vigor. Different methods, which can account for the uncertainty of breeze power output, are

Presented in the first column, while the top row categorizes these methods in tenures of when they are undertaken, i.e., once per day or more regularly. The different methods can be complimentary. For example, more regular and higher resolution commitment and dispatch can be done in place of, or as part of dynamic reserve procurement. In reality, combinations of these different strategies will be employed.

### A. Scheduling Frequency

A more frequent UC, ED, and reserve procurement achieves two things: portion of the procured reserves can be released later and less expensive reserves can be used more often. Increased frequency enables the use of more up-to-date forecasts and real system information. By using updated information, the reserves carried on the system can be reduced as the operating period gets closer, as illustrated by Fig. 2. In general, repeating UC and reserve procurement in the intraday would still require that a 24-hour or longer UC is carried out to accommodate slower starting units and to ensure availability of capacity; however, these schedules should then be updated whenever new information is available. In addition, this approach allows commitment decisions for quicker starting units to be made closer to real time, delaying commitment decisions until more accurate forecasts are available. In effect, fewer units need to be scheduled for startup, which reduces the procurement costs. The rationale for more frequent scheduling was proposed by Schlueter *et al.* in has not been cited in recent literature

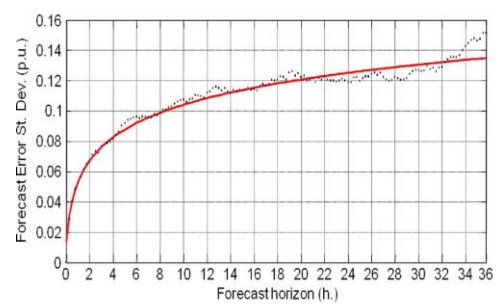


Fig. 1: Normalized standard deviation of breeze power forecast error for 12 GW installed capacity versus forecast horizon.

Tuohy *et al.* [13] show that escalating the frequency of commitment from 6 hours to 3 hours can bring tangible benefits in tenures of cost and reliability in the Irish system; however, modeling limitations prevented any benefits of decreasing the planning period further from being quantified. Similarly, [14] demonstrates benefits when moving from day-ahead to 3-hour ahead gate closure in the UC. More regular UC and ED may also cause some additional costs. Operational costs for some power plants may increase due to diminutive preparation time. This increases the importance of accurate modeling of certain unit constraints, for example, startup times of units, which may be longer than the time between commitments [15]. While research demonstrates benefits for more regular scheduling, in power exchanges the liquidity of the intraday market.

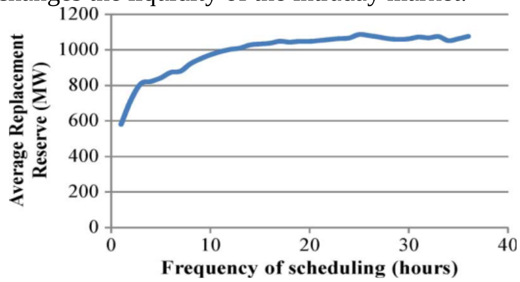


Fig. 2. Example of the trade-off between the reserve requirements and the frequency of commitment [11]. Replacement reserve is similar to the tertiary reserve defined here

has been low—at least in Europe [16]. This hinders the realization of possible benefits from more regular scheduling. One reason is that generators may expect higher profits in the harmonizing market and, therefore, do not bid intraday [17]. They may also be hindered by bilateral contracts. Hence, intraday has been an expensive method to balance forecast errors. This leads to self-harmonizing, which is suboptimal, or to the use of harmonizing markets, which is on average more expensive due to the diminutives response time. Therefore, the results from these models may overestimate the benefits of more regular scheduling

### B. Dynamic Reserve Procurement

Meteorological conditions govern the probable range of breeze power output and breeze power forecast errors also tend to vary with these conditions [19]. As a simple example, if the predicted breeze power output is low, downward error cannot be large. Therefore, a static reserve stratum is not appropriate. Rather, dynamic reserve constraints which are functions of the breeze forecast error and/or the diminutive-tenure variability of breeze power output should be implemented, where the reserve requirement is based on the present stratum of breeze power output, and the expected uncertainty and diminutive-tenure variability of breeze. Taking dynamic reserve allocation as a starting point, the influence of breeze power on different operating reserve categories has been detailed in [20]. In situations with very high stratums of breeze generation where the regulating power plants are being displaced, breeze power plants need to provide the regulation. The alternative is that breeze power plants will have to be curtailed in order to accommodate the minimum generation stratums of the regulating power plant.

### C. Scheduling Resolution

Power systems with a significant amount of breeze power could benefit from higher resolution scheduling (e.g., 5 min instead of one hour). This has been recently implemented in several power systems [31] and in many cases breeze power has been at least a partial motivator. Ramps within the diminutives dispatch interval will be smaller, which enables a reduction of regulation reserves acting within the scheduling interval [32].

## IV. CONCLUSION

Diminutive-tenure vigor harmonizing to manage the variability and uncertainty of breeze power is evolving. Scheduling evolutions including scheduling frequency, dynamic reserve procurement, higher scheduling resolution, and stochastic UC are being proposed and some are being implemented. Frequent scheduling takes advantage of new data closer to real-time and helps to reduce exposure to uncertainty. With more frequent scheduling, the procured reserves can be released later and less expensive reserves can be used more often. Dynamically scheduling reserves reduces the quantity of reserve procurement. Scheduling at higher resolution can reduce the need for reserve, while stochastic scheduling produces solutions which may inherently carry required reserves and are robust against forecast uncertainty. Each of these scheduling evolutions impact on how system operations and decision making can be organized to better manage reserve requirements. Infrastructure developments including increased system flexibility, increased demand side management, interconnection, transmission, larger harmonizing areas, and improved breeze forecasting will also improve diminutive-tenure vigor harmonizing performance. The scheduling evolutions discussed here are tightly coupled and complimentary to the infrastructure developments, and the overall best solution is system dependent and will be detenureined by further research and experience.

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