Advanced Dispatch Optimizer System Roadmap Report

A deliverable specified in the Research and Development Collaboration Agreement between National Grid ESO and Tapestry.

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1. Introduction

As the energy transition continues, more distributed intermittent renewable resources, many with integrated storage, will continue to be connected to the grid and more distributed technologies such as smart home controls and EV charging will continue to alter consumer behavior. This trend will continue to create increasing uncertainty for grid operators in forecasting power system conditions, predicting which hours of the operating day will be most challenging and in developing dispatch control strategies to efficiently manage grid operations in a reliable manner. As this uncertainty increases, traditional dispatch tools and processes will become increasingly insufficient and transformational revision of tools and processes is recommended. This report provides a high-level vision and roadmap to transform dispatch optimization tools and processes by creating integrated digital models of the entire security-constrained dispatch problem.

2. Objective and Scope

The objective of this document is to provide a recommendation on an approach to developing an Advanced Dispatch Optimizer system and to provide a high-level roadmap for such development.

The purpose of this document is to satisfy the second major work product milestone of the Project plan specified in the Research and Development Collaboration agreement between National Grid ESO and Tapestry. The scope of this roadmap report and recommendations focuses primarily on near-term power system dispatch operations which includes the period from four hours ahead through to real-time dispatch operations.

3. Executive Summary

This document provides a summary overview of a recommended advanced dispatch optimizer system that will be necessary to support the transition of power system operations to a supply mix that is lower emission, less flexible, and more distributed. While the power supply mix will become less flexible, largely because of increasing penetration of renewable supply resources that are weather dependent, other resources such as storage technologies, EV charging stations and flexible demand can provide flexibility if properly controlled and incented. Such a system will need to leverage flexible demand and distributed resources to obtain the necessary flexibility to maintain power balance and reserve requirements. In this rapidly approaching future context, comprehensive integrated digital models of the entire security-constrained dispatch problem are required to manage the increasing complexity and uncertainty in power grid dispatch operations caused by the energy transition. Highly accurate real-time and forward-looking models are required to quantify and manage uncertainty using advanced digital technologies and adaptive modeling approaches. Uncertainty will be managed both by improving input data accuracy and by creating probabilistic trajectories to quantify both the magnitude and direction of uncertainty.

The accuracy of key inputs will be improved through machine learning enhanced adaptive models. In addition to data augmentation and cleansing, these models will also provide probabilistic trajectories over several operating hours to quantify key uncertainty ranges. These trajectories will provide grid operators with enhanced situational awareness and more complete understanding of the interactions between various parameters and trends. Net demand trajectories will be created by composite machine learning and consumer behavioral models that will predict behavior patterns in electricity consumption and imbedded DER response[1] based on a variety of indicators. The performance of these adaptive models will be evaluated daily through an automated performance monitoring which will automatically adapt key parameters to improve performance over time and keep the learning models up to date.

The dispatch system requires an advanced and comprehensive transmission model which is a full AC simulation model that can evaluate thermal, voltage and stability constraints in both normal and contingency situations. Adaptive models of transmission security constraints will automatically prioritize the most critical constraints and develop relational control strategies. Full digital models of the distribution grids will be required to provide accurate conditions and flexibility parameters at the transmission delivery substations. Automated orchestration and optimization of devices and resources on the distribution system will enable grid control and flexibility services to be deployed at the system level which can be enabled through aggregators and/or localized transactive markets for key services. At the transmission level, highly automated security constrained dispatch optimization will be enabled through time-coupled mixed-integer programming-based optimization engines that can orchestrate deployment of many small resources, including limited energy storage resources, demand response and other alternative technologies, to create aggregated ramp capability for continuous system control, ramp flexibility and reserve services.

The optimization engines will support both forward looking and real-time functionality. The forward-looking optimization engines are time-coupled engines which project conditions over the next two operating hours and will provide dynamic operating envelopes and scenario envelopes which provide input to and accurately position the

[1] Imbedded (non-visible) DER response will be included in net demand forecast trajectory and visible DERs that participate in market response will be included in DER trajectory

incremental real-time optimization. The real-time optimization will have capability to develop three to five dispatch instruction scenarios for the next five to ten minutes based on the various uncertainty trajectories. The dispatch instruction scenarios will resolve power balance, reserve requirements and transmission constraint control simultaneously. The real-time dispatch model can operate in fully automated mode or in decision assist mode. Fully automated mode will automatically choose and execute optimal dispatch scenario while decision support mode will present the suggested three to five scenarios to the operator for decision on execution of dispatch instructions.

The advanced dispatch system is monitored and controlled through a comprehensive operator visualization and decision support interface. This operator interface provides multidimensional visualization of input data, forecast information, scenarios, trajectories, etc. that provide grid operators with enhanced situational awareness. The interface uses advanced digital technologies to present the most relevant information to grid operators and is configurable for different operational roles (e.g., scheduling, transmission, dispatch). In addition to providing visualization and situational awareness, the interface also provides decision support by presenting solution alternatives through scenario analysis to provide operators with virtual views of the potential results of their decision making in advance.

The advanced dispatch optimizer system will also include comprehensive performance monitoring, evaluation, and feedback mechanisms to improve performance of the system over time through machine learning and operator education. The performance monitoring module will record all information[2] for the entire operating day and will perform an automated analysis to compare projected results and decisions to actual operational outcomes. This process will provide performance assessments of adaptive models, scenarios and trajectory models, optimization engines and operator decisions. The results can be used to tune various components and modules through machine learning techniques, so they perform better in the future and keep learning models up to date. The analytical results can also be used in operator training to improve operators' decision making over time.

[2] Information includes all input data, adaptive model results, scenario results, trajectory forecasts, optimizer results, operator decisions, etc.

4. Conceptual Overview of Suggested Dispatch System Approach

A conceptual overview of the suggested dispatch system approach is illustrated in Figure 1 below. The system consists of three main functional component groups:

A. Machine learning-enhanced adaptive models and advanced digital modeling

The purpose of these modules is to utilize advanced digital technologies to correct, enhance and create high quality input data. The models should have the ability to create scenarios and probabilistic envelopes to highlight key ranges of uncertainty in supply, demand, and system conditions. These adaptive and digital models will ensure the most accurate and complete information is provided to the optimization engines and the system operators. These components include:

i. Adaptive, machine learning enhanced, models to cleanse, enhance and predict key input data based on historic, situational, and probabilistic response characteristics
ii. Digital twin models of the distribution systems which provide highly accurate real-time models that can provide scenario and probabilistic modeling

B. Optimization engines

The purpose of the optimization engines is to solve the security-constrained economic dispatch (SCED)[3] problem to create dispatch instructions for flexible generators, demand resources, storage devices, distributed energy resources and other alternative technologies to satisfy power balance requirements while respecting all transmission security constraints and various reserve requirements. The optimization engines are a series of advanced mixed-integer programming-based solvers. The Look-ahead SCED is a series of optimization engines that are time-coupled and forward looking. Their purpose is to create a realistic resource operating plan and dispatch trajectory for the next two-hour operating period[4]. The solvers will be capable of resolving power balance, reserve requirements and transmission constraints simultaneously. Non-linear transmission

[3] While currently most power system operators have an economic-based objective (e.g., to minimize costs), with appropriate input data, the optimization solvers can also handle other objectives such as minimizing total emissions or could handle multiple objectives such as minimizing costs and emissions based on specified prioritization.
[4] The time periods of Look-ahead SCED shown in Figure 1 are illustrative, the look-ahead period and optimization intervals will be adapted based on the specific power system resource characteristics.

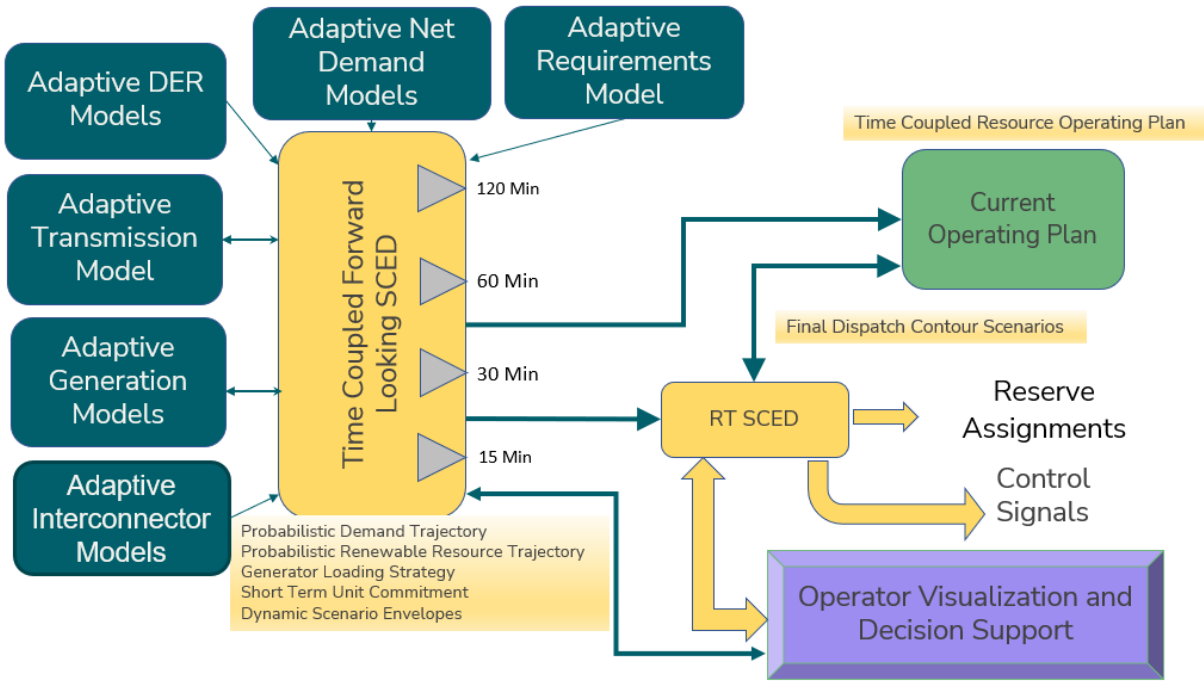
constraints (e.g., voltage constraints) will be linearized near the operating point to model the constraint accurately in the optimization through an iterative approach.

The real-time SCED is a focused incremental optimization formulation around the current operating point to create final dispatch contour scenarios, one which will drive the dispatch instructions sent to resources upon approval by the balancing system operator. The real-time SCED will also resolve power balance, reserve requirements and transmission constraints simultaneously. This model will be capable of evaluating three to five scenarios for the next five to ten minutes based on the various uncertainty trajectories. The real-time dispatch model can operate in fully automated mode or in decision assist mode. Fully automated mode will automatically choose and execute the optimal dispatch scenario while decision support model will present the suggested three to five scenarios to the operator for a decision on the execution of dispatch instructions.

C. Operator Visualization and Decision Support

The purpose of this module is to provide a single interface where operators can view data and information with enhanced multi-dimensional visualization tools to significantly improve situational awareness. The module also includes decision support visualization and tools that suggest corrective actions and beneficial or optimal choices for the operator to consider. The tools allow operators to view scenarios rapidly and make decisions.

Figure 1 – Conceptual Overview of Suggested Dispatch System



5. Primary System Components

The recommended primary system components are explained in this section.

A. Adaptive Input Data Models

Adaptive input models include the Adaptive Generation Model, Adaptive Transmission Model, Adaptive Interconnector Model, and the Adaptive Distributed Energy Resource Model. The models utilize advanced digital technologies to correct, enhance and create high quality input data. The models should have the ability to create scenarios and probabilistic envelopes to highlight key ranges of uncertainty in the input data.

Adaptive Generation Model

The purpose of this model is to correct, enhance and create generation input data for both thermal generation and grid scale renewable generation resources. Market participants nominate generation MW schedules for each hour of the operating day and submit offer parameters that specify the parameters (e.g., price, quantity, notice time, etc.) under which the grid operator can move the generator from their nominated schedule to assist in balancing the power supply and demand and in resolving transmission security constraints.

The adaptive model for thermal generation will utilize advanced data analytics and digital technologies to evaluate the historic performance of each thermal generation resource to create a model of the resource. The model will be capable of evaluating generator's performance correlated to a variety of indices including weather, power system conditions, generator condition, and dispatch state[5]. This model can be used to correct the generator's input data (e.g., MW limits, ramp rates, etc.) and to enhance the data by filling in missing information. The model can also be used to create a probabilistic response model and trajectory for the generator over the current and upcoming operating period. It can be useful to accurately predict the generator's response to dispatch instructions under a variety of scenarios.

The adaptive model for intermittent renewable generation will utilize advanced data analytics and digital technologies to evaluate the historic performance of each generator. The model will be capable of evaluating generator's performance correlated to a variety of indices including weather, generator owner's production forecasts and generator condition. The model will be capable of comparing the generator owner's forecast of production with actual production and correlate these results over a variety of weather indices and other factors. The model can be used to create a probabilistic forecast model and trajectory over the current and upcoming operating period.

To begin to create the adaptive generation models, at least one year's worth[6] of historic data for each generator will be required including all generator offer data and forecast data for each hour, the generators nominated and instructed MW output and actual MW output for dispatch interval[7]. Additional information required is as follows: Hourly weather data for each generator location, generator maintenance information, total system demand, binding transmission constraints.

Several grid operators have a simplified form of adaptive generation models in operation currently. However, these models are only capable of performing automated data cleansing to correct bad input data parameters. The automated data cleansing is beneficial because it provides operators with

[5] Dispatch state is the condition of dispatch signal to the generator, can be ramping up, holding, or ramping down.

[6] While one year's worth of data is likely sufficient to cover most operational, weather and market circumstances and will strike a balance between model accuracy and data gathering complexity, even more historic data is generally beneficial to the process of developing maine learning models.

[7] Need at least hourly data but preferably more granularity such as each sub-hourly dispatch interval

more confidence in the information and relieves them of the burden of manual data correction. However, these existing implementations are not predictive models and do not utilize advanced machine learning algorithms or techniques.

The benefit of implementing advanced adaptive generation models is significant because it provides a much more accurate digital model of each generator and can better predict the generators response under a variety of scenarios. These enhanced models significantly improve performance of optimization through developing highly accurate input data and they improve system operator situational awareness and confidence in the fidelity of generation data.

Adaptive Transmission Model

The purpose of this model is to monitor the real-time transmission flows, flow trends and transmission system conditions; to develop a set of prioritized transmission constraints, including thermal, contingency, voltage, and stability constraints for consideration by system operators and the optimization algorithms. The adaptive transmission model will be highly automated and will develop transmission control strategy scenarios which will streamline presentation of transmission constraints to all other dispatch tools including the optimization algorithms. These activities provide significant benefit by improving the speed and efficiency of dispatch optimization engines and by developing summary level control strategies to enhance situational awareness for transmission operators.

The adaptive model for transmission evaluates near-term transmission line flow trends on transmission lines that are, or projected to be, at their normal or contingency-based operating limit within the current operating period. The model tracks the transmission facility loading trends over the last few hours of operation and evaluates the rate of change of actual and expected flow versus limit and suggests control strategies to mitigate the severity and cost of the managing constraint. It groups, ranks, and prioritizes active transmission constraints to develop a control strategy based on trajectory and interaction with other constraints and with control variables. This minimizes the number of emergency level control requirements and improves optimization efficiency. For voltage and stability constraints, on-line AC power flow analysis is used to provide updated linearized pre-contingency flow limit surrogates that are linearized at the current operating point to increase accuracy[8]. The adaptive transmission model will develop dynamic long term and short-term ratings for lines and transformers based on up-to-date system conditions, it will not be designed to suggest switching or substation reconfiguration options, that activity will be handled in the SCED modules.

This model requires a fully detailed on-line transmission model, down to the transmission/distribution interface substations, with steady state and transient simulation and analysis capability. The model should receive input from various off-line transmission studies.

Several grid operators have implemented adaptive transmission models which serve as a decision support tool for operators to prioritize and select constraints that must be mitigated. These implemented applications are not highly automated but are useful support tools.

Adaptive Distributed Energy Resource Model

This purpose of this model is to correct, enhance and create distributed energy resource input data for all DER resources that are visible and participating in the market[9]. The DER can be either individual resources or aggregated resources in a single transmission location.

The adaptive model for DERs will utilize advanced data analytics and digital technologies to evaluate the historic performance of each DER resource to create a model of the resource. The model will be capable of evaluating the DER 's performance correlated to a variety of indices including weather, power system conditions, resource condition, and dispatch state[10]. This model can be used to correct the DER's input data and to enhance the data by filling in missing information. The model can also be used to create a probabilistic response model and trajectory for the resource over the current and upcoming operating period. It can be useful to accurately predict the resource's response to dispatch instructions under a variety of scenarios.

To begin to create the adaptive DER models, at least one year's worth of historic data for each DER will be required including all offer data and forecast data for each hour, the resource's nominated and instructed MW

[8] The calculation of surrogate linearized limits to represent non-linear constraints, such as voltage constraints, is performed at the current operating point because small movements along the nonlinear limit curve can be more accurately approximated by a linear limit.

[9] Note the Adaptive DER Model focuses on distributed resources that are offered into the market and are therefore visible to system operators, imbedded DER resources that are not visible are handled in the Adaptive Net Demand model and of course larger intermittent resources are handled in the adaptive generation model.

[10] Dispatch state is the condition and type of dispatch signal to the resource.

output, and actual MW output for dispatch interval[11]. Additional information required is as follows: Hourly weather data for each location, resource maintenance information, total system demand, binding transmission constraints, including distribution level constraints if applicable. As the model becomes more developed and mature, its performance can be improved with real-time meter and sensor data including weather sensors to improve distributed renewable resource modeling.

To our knowledge, no such adaptive DER modeling approach has been implemented by a Grid Operator.

Like the adaptive generation model described previously, the development of adaptive DER models provides significant benefit because it provides a much more accurate digital model of each DER resource and can better predict its response under a variety of scenarios. These enhanced models significantly improve performance of optimization through developing highly accurate input data and they improve system operator situational awareness and confidence in the fidelity of DER data.

Adaptive Interconnector Model

The purpose of this model is to create predictive models of interconnector flows. This module will monitor the real-time power flows on transmission interconnectors, Interconnector scheduled MW, scheduled and actual flow trends and power market conditions in the GB market and in the remote market[12]. The model will analyze this information using advanced data analytics and digital technologies to create a probabilistic response model and trajectory for the interconnector flows under a variety of scenarios. This model would be beneficial to provide operators with more accurate forecasts of interconnector flow and capabilities.

To our knowledge, no such adaptive interconnector modeling approach has been implemented by a Grid Operator.

Adaptive Requirements Model

The purpose of this model is to dynamically calculate reserve requirements based on actual system conditions. Currently these reserve requirements calculations are static parameters that are not frequently updated, and automated approach to performing these calculations based on changing

[11] Need at least hourly data but preferably more granularity such as each sub-hourly dispatch interval
[12] The remote market is the foreign power market to which the interconnector is connected.

system conditions is recommended to ensure reserve requirements are kept up to date under rapidly changing and uncertain system conditions. These reserve requirements are defined based on power system characteristics such as the size or power output of the largest generator currently operating, the amount of power being imported on a single interconnector, the size of the largest demand contingency, etc. One benefit of automating this process will give system operators more confidence that the reserve levels are consistent with system conditions and will augment situational awareness. Another benefit is that updated dynamic reserve requirements will improve dispatch efficiency and the efficiency of the optimization algorithms. A high-level summary of the purpose of operating reserve requirements is provided below. A description of reserve deployment techniques utilized by various grid operators around the world is provided in Appendix 1 which provides a summary benchmarking analysis.

The power grid must be operated in a safe and reliable manner. To maintain efficient grid operations within established reliability criteria, grid operators define reserve requirements and operating margins. The reserve requirements are satisfied by procuring various reserve services for generators, demand resources and alternative resources, a summary of the common reserve service categories is as follows:

- Frequency Containment Reserves (FCR) - This is the first response to frequency deviations; its purpose is to fine tune frequency and correct for small frequency changes due to short term fluctuations in supply and demand. FCR is usually an automated response within seconds to short term frequency imbalances.
- Frequency Restoration Reserves (FRR) - Purpose is to keep reserves available to respond to restore system frequency following a contingency event and larger frequency excursion. Response times are in the three-to-ten-minute range.
- Replacement Reserves (RR) - Additional energy that can be called upon to restore frequency restoration reserves in the event of a contingency event. Can be thought of as the ‘headroom’ that the operator has to re-balance the system after a significant event. Response times are in the ten-to-thirty-minute range.

B. Advanced Net Demand Forecast Module

The purpose of this model is to create forecasts, probabilistic trajectories, and scenarios for Net Demand at a substation, regional and total market level. This model has the following components:

- Adaptive Demand Forecast and Consumer Behavior Model
- Adaptive Imbedded DER Models

The adaptive demand forecast and consumer behavior component tracks historic performance of demand forecasts as compared to actual demand[13] to develop a model of demand forecast performance. The model is developed using advanced data analytics and machine learning techniques. The model evaluates demand forecast performances and correlates to a variety of indices such as weather information, market prices, day, time of day, etc. The model should be capable of developing probabilistic trajectories and scenario envelopes.

The adaptive imbedded DER models are developed by utilizing existing and innovative data sources to estimate the amount and type of embedded DER at each transmission substation. This model is also developed using advanced data analytics and machine learning techniques in an equivalent manner to the models previously described, however access to distributed data and information will be a challenge. The model can be enhanced by working with distribution companies, distributed DER aggregators and other innovation companies to enhance models through access to information. As described in the following section, working with distribution companies to develop digital models of each distribution system will significantly improve the performance of imbedded DER modeling.

The benefit of developing such models is to improve the accuracy of the net demand forecast which will improve operator confidence in the forecasts, situational awareness, and overall performance of dispatch algorithms.

To our knowledge, no such adaptive net demand modeling approach has been implemented by a Grid Operator.

C. Digital Model of Distribution Systems

The development of a digital twin model of distribution systems is best accomplished through the distribution utility and would be enhanced by collaboration with the other entities such as aggregators, innovation

[13] Actual demand is net demand minus imbedded DER activity.

companies and consumer groups. The term digital twin is often used and not necessarily well defined. For this paper, we define a digital model of a distribution system to be a model of the system that is capable of real-time steady state and transient simulation of the distribution grid, near real-time scenario-based simulation and forward-looking simulation. The digital model of the distribution system would be complimented with digital models of the DER and other devices connected to the system. Thus, to achieve the full potential of a digital model of distribution systems, a comprehensive approach is required to develop models of both the distribution grid itself and of the active devices connected to it. This model integration approach would allow incremental and complimentary development of the modeling capabilities. For initial development of an advanced dispatch optimizer, a digital model of distribution systems will be sufficient but leveraging the capabilities of distributed resources more fully will require orchestration of DERs in a unified manner. Ultimately, the comprehensive digital model of the distribution system would support orchestration of devices and DER connected to the system through utility control signals and/or with aggregators through transactive marketplaces. This would enable more accurate digital modeling of the DER response which would enhance the overall accuracy and value of the model. Obviously as digital models of distribution systems evolve, there will be different levels of granularity in modeling based on the characteristics of each distribution system.

The development of a digital model of the distribution system is a complex and large-scale effort so an incremental approach to the problem is warranted. A suggested incremental approach is provided below.

1. Begin by engaging with one distribution utility partner to facilitate their development of an accurate model of their entire distribution grid including both primary and secondary circuits. This process can be accelerated or enhanced using innovative methods and data sources including auto-topology algorithms.
2. Develop/acquire real-time simulation capability for this distribution grid model for both steady state and transient. There are several existing simulation software packages available for distribution grids.
3. Develop and enhance time series data and alternative data sources through partnerships with innovation companies, aggregators, sensor deployments and other means
4. Develop scenario modeling capability.
5. Develop orchestration capability to control DER devices through either an operational signal or price signal. This could also be

performed by aggregators or more likely will be performed in coordination with aggregators. This effort can be coordinated with and done in parallel with transactive market developments.

6. Explore development of local transactive markets, either through aggregators or technology. This effort can be done in parallel with item 5. These price signals can coordinate and enhance DER response.
7. Once the digital model development has been demonstrated with one partner, scale to process to include additional distribution utility grids.
8. Develop hierarchical control approach to maximize effectiveness of DER capability delivered to the transmission substations.

D. Time Coupled Forward Looking Security-constrained Dispatch Optimization Module

The purpose of this model is to develop a forward-looking operating plan to optimize and control deployment of generators and many small resources, including limited energy storage resources, demand response and other alternative technologies, to operate the power system in a reliable, cost-efficient, and low emission manner. The model will perform time-coupled security constrained optimization to create an operating plan for the upcoming operating hours that satisfies power balance requirement, transmission security constraints and all reserve requirements simultaneously. It will be capable of setting the stage to create aggregated ramp capability from small resources for continuous system control, ramp flexibility and reserve services.

The model is deployed using a series of optimization engines that utilize mixed integer programming algorithms which are interfaced together to solve a series of security-constrained economic dispatch problems[14] over a two-hour forward looking time horizon. The solvers must be capable of co-optimizing to satisfy energy and all reserve requirements while respecting all transmission security constraints[15] and generation constraints. The optimization engines are configured to solve security constrained dispatch problems at various intervals[16] and are interfaced, or

[14] The optimization objective function could also incorporate minimizing emissions or other factors instead of or in addition to minimizing cost.

[15] As discussed in the adaptive transmission model section, non-linear transmission constraints, e.g., voltage or stability, are linearized at the projected operating point and presented to the optimization through and iterative approach.

[16] The intervals of 15,30,60,120 minutes shown in Figure 1 are illustrative, the time intervals are flexible and can be selected by operators based on system conditions.

coupled, in time such that the initial conditions of each optimization problem in the series can be set based on previous or upcoming conditions. This time-coupling is a key innovation that can allow the forward-looking dispatch module to create a realistic dispatch trajectory over time. Additionally, the model should have the capability to optimally deploy short term limited energy resources, such as batteries and demand response, to create aggregated ramp capability.

This type of forward-looking time coupled optimization model has been deployed at several grid operators, but the functionality is limited to generation resources. There is no implementation of such an approach that manages optimization of limited energy resources in a time-coupled manner.

Day-ahead scheduling

Since the forward-looking SCED module of the advanced dispatch optimizer will have the capability to perform unit commitment, a version of this module can be extended and adapted to perform day-ahead scheduling using a similar integrated optimization. This can be accomplished by creating offline versions of the module coupled with day-ahead transmission models and day-ahead reserve requirements.

E. Real-Time Security-constrained Dispatch optimization Module

The real-time security constrained dispatch module is an integrated optimization engine that utilizes a mixed integer programming-based algorithm to solve the near-term security-constrained dispatch problem that co-optimizes energy and reserve dispatch while respecting transmission security constraints. This module should be capable of executing at least every 5 minutes to create the final set of dispatch instructions for generation and alternative resources which should be sent out automatically upon approval of the solution by the operator.

The module should also be capable of producing multiple final dispatch contour scenarios which provide the system operator with the flexibility to choose which scenario is best to satisfy current system control requirements while enforcing all security and reserve constraints. The module should be capable of operating in fully automatic mode or in decision support mode.

In fully automatic mode the module will develop power balance scenarios based on current operational trajectories and using inputs and probabilistic scenarios developed by the look-ahead dispatch module. The model will then solve the appropriate number of scenarios, automatically analyze them, and decide which scenario is best to confirm and execute. Once the scenario is approved by the automated selection procedure, the dispatch instructions will be automatically sent out to all resources. In this automated mode, the operators can monitor the operation of the real-time dispatch module and can switch to decision support mode if desired.

In decision support mode, the module will provide the operator with suggested power balance scenarios based on current operational trajectories and scenarios developed by the look-ahead dispatch module. The operator will be able to choose the scenarios and modify them if desired through the decision support interface. The module should be capable of presenting at least four power balance scenario results to the operator for final decision. Once the operator selects and approves one of the scenarios, the dispatch instructions will be automatically sent out to all resources. This mode of operation allows the operator to make the final key power balance decisions that allows operator discretion and judgement. Decision support mode will also be useful during abnormal system events or when operators are notified of upcoming events that are not sufficiently modeled in the system.

Whether operated in automatic or in decision support mode, the real-time security constrained dispatch module automatically creates solutions to the dispatch problem that are consistent and simultaneously feasible with all transmission and generation constraints. No operator intervention should be required to maintain transmission system security in normal and contingency operational circumstances.

This type of integrated real-time dispatch optimization has been implemented by several grid operators utilizing a decision support type approach. However, these implementations generally do not have the level of automation and scale of the approach recommended in this report. These existing systems are not capable of operating in a fully automated mode.

<u>Frequency Control</u>

Most grid operators utilize Automatic Generation Control (AGC) to keep frequency within established bandwidth. AGC is a system for automatically adjusting the power output of generators in response to changes in system frequency. Reliable and stable power grid operations require that load and generation are closely balanced minute by minute. If more power is being generated than consumed, all generators in the system begin to speed up which increases system frequency. Conversely, if less power is generated than consumed the generators slow down which decreases system frequency. The AGC system senses such system frequency changes and automatically changes generation output to keep load and generation in balance and frequency stable.

It is recommended that this advanced dispatch optimizer system utilize AGC for frequency control because an automated control system will become more necessary to control frequency response in the grid of the future as more distributed resources are utilized for frequency control. Although integrating AGC into the advanced dispatch optimizer is recommended, the optimizer system can function without such integration provided some alternative method of automated frequency control is implemented.

Dispatch Approach

An integrated security constrained economic dispatch system works most efficiently and is most flexible by using a dispatch set point approach, The module can be adapted to work using the closed Bid Offer Acceptance (BOA) dispatch approach that is currently utilized in the UK market by utilizing the 30-to-60-minute look-ahead dispatch module results to enable the RT SCED to develop closed BOAs for generators. However, as discussed more fully in section 9, this approach will be less efficient and will likely become less feasible as the energy transition continues and additional thermal generation resources retire.

F. Operator Visualization and Decision Support Module

The purpose of this module is to provide a single interface in which operators can view input data, probabilistic trajectories, input scenario information, optimization results and scenarios, dispatch envelopes, etc. This module displays results with enhanced multi-dimensional visualization and provides visualization tools to significantly improve situational awareness. The tools allow operators to rapidly view dispatch scenarios and related information to interpret system conditions and control parameters to make decisions. The module will provide multidimensional visualization of power system conditions, trends, probabilistic trajectories, and scenarios to enhance situational awareness for all control room staff including operators, transmission analysts and other key personnel. The module also provides suggested control actions based on key information and correlated trends that assist operators in key decision-making activities.

This comprehensive data visualization module will receive and process data from the adaptive input data modules, the adaptive net demand module, the forward-looking security-constrained dispatch optimization module, and the real-time dispatch optimization module and will apply advanced data and information visualization techniques to enhance the situational awareness of operators, transmission engineers and other key operational experts. This visualization approach will be designed to allow operators to comprehend and interpret large amounts of data and information more intuitively and make decisions on complex situations more rapidly. The module will also utilize advanced data analytics and machine learning to develop suggested control actions based on current operating conditions.

G. Performance Monitoring Module

The purpose of the Performance monitoring module is to perform a daily performance review of the integrated advance dispatch optimizer system and its components including the adaptive input data models, the adaptive net demand module, the look-ahead and real-time security constrained dispatch optimization modules and the decision support module. It will also evaluate operator decision actions. The module will review performance of each component and of the system as a whole and will perform automated tuning of the machine learning modules. It will generate daily reports for review by operational support staff which will aid them in monitoring the system and key performance trends. It will also provide anomaly reports and suggest potential improvements in other modules and/or system configuration adjustments. The module will review operator actions and suggest training scenarios and opportunities for improvement.

6. Data Requirements

The advanced dispatch optimizer system will require significant amounts of data for a variety of timeframes and from a variety of sources. This section will only discuss transmission level information, digital modeling of distribution is discussed in previous sections. Data requirements for adaptive input data models are discussed in those relevant sections of the report. The purpose of this section is to provide a general indication of the categories of data required for development of advance dispatch optimizer; it is not intended to be a detailed comprehensive data specification.

<u>Power System Characteristic Data</u>

This data is needed to model both the physical and electrical characteristics of the power system. It includes the following categories:

- Transmission System Information
  - Geographic location information for transmission lines, transformers, substations, generators, etc.
  - Network topology / connectivity information / Voltage Levels
  - Transmission line and transformer physical attributes (e.g., impedance, ratings, etc.)
  - Substations that have boundary connection to distribution
  - Transmission reliability requirement standards, including thermal limit control standards, frequency control standards, voltage control standards and contingency definitions
- Generation Information
  - Geographic location information
  - Physical Attributes (e.g., Maximum/Minimum Power output, impedance, etc.)

Real-time and Time Series Data

This data is changing over time and is either metered or estimated, examples include the following:

- Generation MW, MVAR
- Bus Voltage, Angle
- Demand MW, MVAR (by substation)
- Line flows
- Equipment Status
- Transformer tap settings

Market and Offer Data and Schedule Nominations

This data is submitted by market participants either day-ahead, in-day or hourly, examples include the following:

- Generation MW schedule and offer data MW, price for adjustments
- Demand Schedule
- DER and flexible demand bid data
- Reserve resource schedules and offers

Forecast data

The advanced dispatch optimizer system will generate probabilistic trajectories and scenario forecasts. These functions will require forecast information from market participants and other sources to provide the basis for development of adapted forecasts. Required forecast information examples include:

- Net Demand Forecasts (total system, Regional, Substation level)
    - Demand / Consumption Forecasts
    - Imbedded DER forecasts
- Weather Forecasts
- Renewable Resource Production Forecasts (resource level)

External system and market data

This information is required to feed into the adaptive interconnector model and to support adjustments to interconnector schedules of flows. Examples of this data include:

- Interconnector flow schedules,
- External market transaction schedules and offer information
- External Market prices and aggregate supply/demand conditions

Historic Data

As discussed in previous sections a significant amount of historic data is required to develop adaptive input data models. The scope of historic datasets includes all data categories listed above. The historic data is needed for development of adaptive input data models, to define data ranges for data cleansing analytics and to train adaptive machine learning models.

Analysis of SORT Data

Since this engagement was, in part, a scoping experiment for Tapestry to understand the dispatch problem, the intent was to explore multiple methods to understand the scope of current dispatch operations. The intent was to deploy data analytics and optimization algorithms to analyze the SORT datasets to get a complete picture of dispatch operations. While we gained some key insights and learning from the datasets, as the scoping project proceeded it became clear that the data provided was only a subset of the information necessary to perform the power system scheduling and dispatch functions. There are several other systems, like transmission analysis, reserve deployment, demand aggregation, etc. that are used to provide information to operators to guide their decisions and operators utilize several manual processes that are not captured in data. Once we analyzed the SORT datasets, we concluded that data analytics alone would not provide sufficient insight into the current dispatch problem, and we decided a better approach would be a process of interviewing key NGESO experts. This interviewing process gave us a rich understanding of the current processes and the challenges faced by the grid operators. This understanding was vital to the development of the Advanced

Dispatch Optimizer system design and Roadmap toward the future that is summarized in this report.

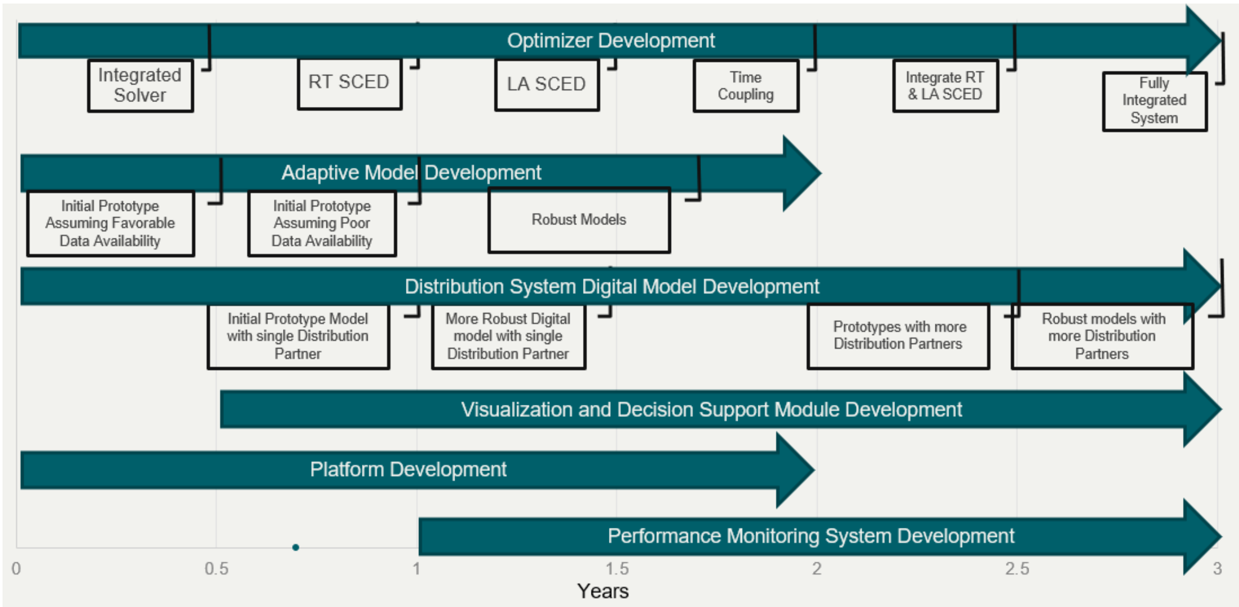
7. Incremental Approach Roadmap

The development of the advanced dispatch optimizer system described in this report will be a large and complex multifaceted project. This section provides a suggested phased approach and incremental steps to ultimately achieve the vision outlined in this report. This phased approach would enable some modules of the system to be developed and implemented in stages to make incremental improvements in dispatch tools and processes while the total system is developed over time. This phased approach would also be beneficial to allow testing and exploration of the benefits of system components through rapid prototyping and incremental development.

An overview of the phased development over an aggressive three-year timeline is illustrated in Figure 2. **While the development of the system could be accomplished under this aggressive timeline, other factors such as implementation of a day-ahead scheduling process, potential market rule changes, and incorporation of the advanced optimizer system into existing control room processes would likely extend implementation time period to four to six years total.** Under this phased approach, work should begin in parallel at project start on the optimizer, adaptive models, digital modeling of a single distribution system and the technology and data platform. Productive work on the visualization is dependent on having a few working adaptive model prototypes so the work on this module should wait until the adaptive model prototypes are operational. Similarly, work on the comprehensive performance monitoring module is dependent on having all adaptive model prototypes operational and RT SCED operational so the work on this performance module should wait until these milestones are met. However, it is noted that performance monitoring and feedback mechanisms are inherently included in each adaptive model as part of the machine learning algorithms and processes. The comprehensive performance monitoring will be focused on the integrated performance of the various modules.

The three-year timeline illustrated in Figure 2 is aggressive and is likely the shortest feasible timeline for such an effort. Considering the timelines for resourcing and funding processes, and the need for development to be integrated, where possible, with existing and planned systems, the overall timeline will likely be longer in practice.

Figure 2 – Overview of Incremental Approach Roadmap via an aggressive three Year Development Approach

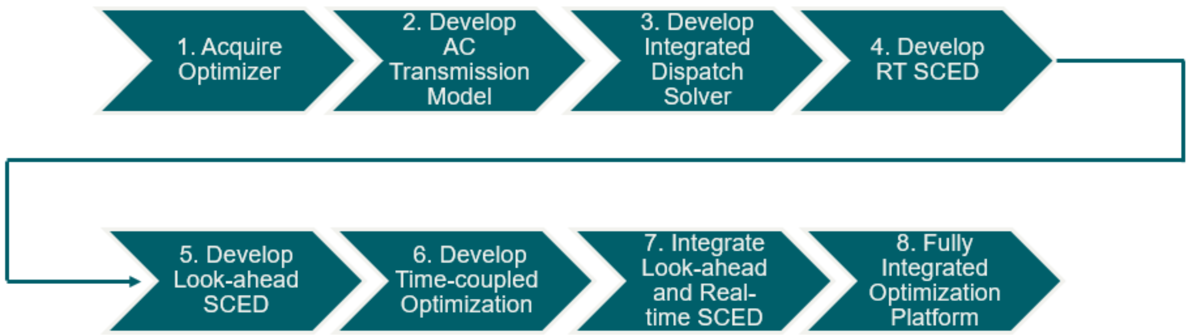


<u>Optimizer Development</u>

The first activity in the advanced dispatch optimizer system development should be focused on development of an integrated optimization platform. A phased approach to developing the integrated optimization platform is illustrated in Figure 3.

As noted below, upon completion of phase 4, the RT SCED module could be deployed in the control room as a stand-alone module and upon completion of phase 5 the LA SCED could also be deployed as a stand-alone module. Such advanced deployment would be beneficial to provide enhanced functionality to operators more quickly, to gain acceptance and to act as advance training and familiarity in preparation for the end state integrated system. Although the phased deployment approach could be optional, it is highly recommended to deploy these systems in a phased approach to facilitate the transition to a more advanced dispatch optimizer approach. A description of each incremental phase of development is provided below.

Figure 3 – Development of Integrated Optimization Platform



1. Acquire Optimizer – Purchase state-of-the-art Mixed Integer programming-based optimizer. There are several high-quality commercial solvers available that are in use in power grid operator control rooms. The solver must be capable of solving large-scale integrated security constrained dispatch problem, with co-optimization of energy balance and reserve requirements, within 1 to 5 minutes.
2. Develop AC Transmission Model - Verify and improve functionality of full AC transmission model and on-line stability model. These models need to be online, operational models that can perform full-scale transmission contingency analysis for all contingencies within five to ten minutes.
3. Develop Integrated Solver - Develop Integrated model of dispatch problem in the optimizer. This requires modeling of energy balance, reserve requirement and all normal and contingency transmission constraints simultaneously in the solver to co-optimize energy balance and reserve requirements while respecting all transmission limitations.
4. Develop Real-time SCED – The Real-time security-constrained economic dispatch should be an incremental optimization formulated around the current operating point that will perform co-optimization of energy balance and reserve requirements subject to current trending transmission constraints. This phase should include validation of the accuracy and performance of the real-time SCED module to meet operational specifications. Once the RT SCED is operational and performance verified, it could be deployed in operations as a standalone system.
5. Develop look-ahead SCED – The forward-looking security-constrained dispatch needs to be capable of co-optimizing energy balance and reserve requirements while respecting all transmission limitations looking forward over the upcoming operating period (between 15 to 120 minutes into the future). This phase should include validation of the accuracy and performance of the look ahead SCED module for various snapshots in time to meet operational specifications. Once the LA SCED is operational and performance verified, it could be deployed in operations as a standalone system.
6. Develop time-coupled optimization – This phase includes setting up an architecture to execute multiple snapshots of the look-ahead optimization engine and coupling them across time such that each solution is consistent with previous

and future solutions. This time-coupled architecture must also be capable of orchestrating and optimizing limited energy resources such as batteries across the dispatch trajectory. This phase should include validation of the optimal deployment of limited energy resources

7. Integrate look-ahead and real-time SCED – This integration phase will set up the real-time SCED so that it can receive trajectory dispatch information from the look-ahead SCED as an input to improve performance of real-time SCED and add scenario processing functionality to real-time SCED. Once the LA and RT SCED are integrated and performance verified, they could be deployed in operations as an integrated system.
8. Fully Integrated optimization platform – In this phase the fully integrated platform, including adaptive model inputs and visualization / decision support tools, is developed and tested.

Adaptive Input Data Model and Adaptive Net Demand Model Development

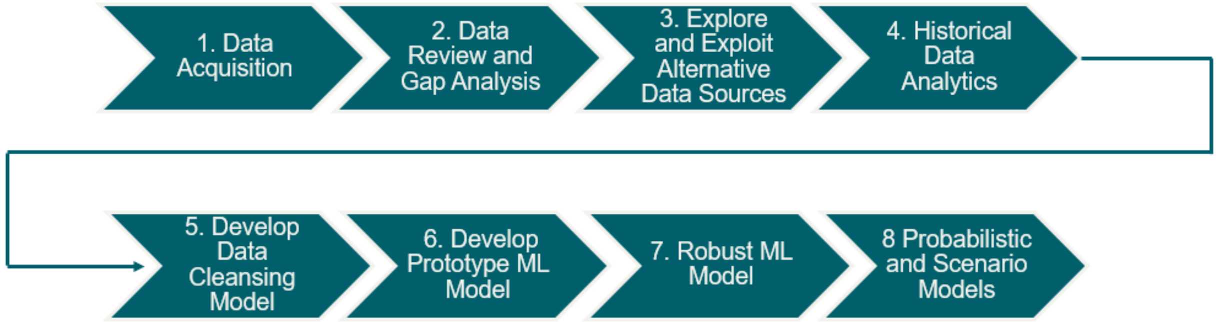
Development of the adaptive input data models and the adaptive net demand model should commence in parallel with the optimizer development. Development of all adaptive models should begin in parallel, but it should be recognized that progress toward development of an initial prototype for each may vary depending on the availability and quality of historic data. Complete historic information availability is important to development of machine learning models. The development of the following adaptive models should all proceed in parallel to quickly identify and mitigate any data acquisition issues which could inhibit or delay progress.

- Adaptive DER Model
- Adaptive Transmission Model
- Adaptive Generation Model
- Adaptive Interconnector Model
- Preliminary Development of Adaptive Net Demand Model

As explained previously, there is a beneficial interaction between development of the adaptive net demand model and developing digital model of distribution grids, however preliminary development of adaptive net demand model is recommended at this stage to begin basic data acquisition, gap analysis and exploration of alternative data sources.

A general incremental approach to developing adaptive, machine learning-based models is illustrated in Figure 4.

Figure 4 – Development of Adaptive Machine Learning Models



As illustrated in Figure 4, the development adaptive machine learning models is a comprehensive process that begins with acquiring the necessary available data then reviewing the data and identifying critical data gaps. Once data gaps are identified then a process to explore and leverage alternative and innovative data sources is recommended. After these steps, a comprehensive analytical analysis of historical data is performed which will identify data characteristics, ranges, trends, and other indices which will be helpful in developing data governance screening and data cleaning processes. After these steps are completed the prototype machine learning model is developed and tested followed by a more robust machine learning model development on expanded data. Finally, advanced data analytics processes are used to develop algorithms that can provide probabilistic trajectories and scenario envelopes. Once the prototype adaptive models are operational, they could be deployed as advisory tools in operations. The incremental advanced deployment of these prototype adaptive models in control room operations is a recommended approach to gain acceptance and begin to familiarize control room staff with adaptive model capabilities and functionality. Such deployment could also have significant incremental benefit in operations to provide insights into input data trends.

Data and Technology Platform Development

An integrated, well-governed common data platform is necessary to achieve the advanced dispatch optimizer vision. To achieve "perfect" data and models, it is necessary to integrate multiple dissimilar data sources and to explore innovative and alternative data sources. Since data silos inherently limit the usefulness of data, a common platform is necessary to unlock value and streamline data access for all adaptive models. In such a system, strong data governance and security are critical to achieving desired results in an efficient and secure manner.

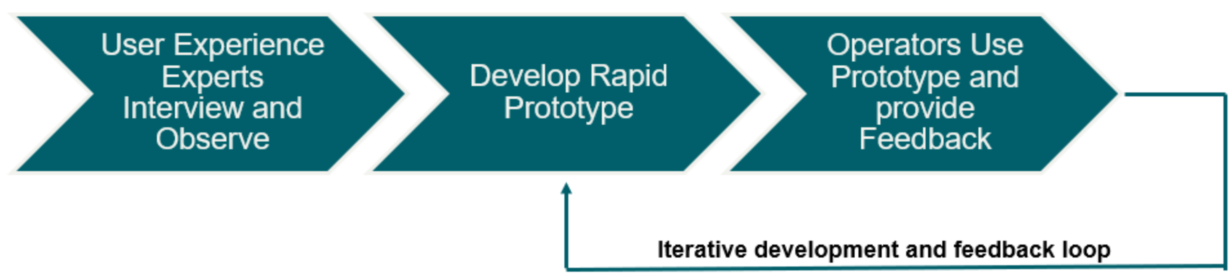
An integrated technology platform with open architecture that supports flexible and modular component development and adaption is also critical to success of the vision. **The technology platform development should also incorporate development of a backup strategy and dual primary systems for optimizer and other key modules to ensure high availability of the system.** The platform should be developed in parallel with optimizer and adaptive model development so that it is ready to integrate these modules as they become available in prototype stages and beyond. Parallel development will also allow designs to be adapted as key learning are developed.

Advanced Visualization and Decision Support Tool Development

After prototypes of some or all the adaptive input data models are developed work should begin on the enhanced visualization module development. Development of portions of this module should also be tied to development of the integrated look-ahead and real-time optimization prototype.

The recommended process for developing impactful visualization tools involves rapid prototyping and iterative development to maximize the ability for developers to understand the user experience. The rapid prototype iterative process is illustrated in Figure 5. It is recommended this process also be followed for development of the decision support interface that will be utilized to control the Integrated Optimization platform. As certain development milestones are achieved in visualization approaches, incremental prototype deployment of these visualization tools into the control room as an advisory tool is recommended. this advanced deployment will be helpful to begin the process of training and familiarization which will ultimately improve the transition to the advanced dispatch optimizer approach.

Figure 5 – Rapid Prototype Iterative Process for Visualization Tool Development



Performance Monitoring Module

After an initial prototype of the integrated advance dispatch optimizer system is in place, development of the comprehensive performance monitoring module can begin. It is important to note that performance monitoring and feedback mechanisms are inherently included in each adaptive model as part of the machine learning algorithms and processes. The comprehensive performance monitoring module leverages the individual adaptive model performance monitoring processes but also evaluates overall integrated system performance and the various important interactions between the modules of the entire advanced dispatch system. It is recommended this module is developed utilizing the rapid prototyping method described in the previous section.

8. Dispatch Roles and Processes

The vision of the advanced dispatch optimizer is to create an integrated platform that combines the various aspects and processes of power system operation into a single integrated and optimal approach. This approach will transform power system operations in to a much more automated and optimal process that will leverage the flexibility of thousands of distributed devices. This system will automate the creation of dispatch scenarios and transmission control strategies and will streamline interaction between various dispatch functions. While the system will be highly automated, the expertise of highly trained control room operators will still be needed to monitor and provide key control inputs to the advanced dispatch optimizer. The key functions of power balance, frequency control, reserve monitoring and deployment, and transmission security will remain necessary but will be executed in a more integrated and automated manner.

Currently NGESO performs the following three major control room functions separately:

- Strategy team – develop the system operating plan, to meet energy margin and transmission constraint requirements, in scheduling timescales

- Transmission team – conduct contingency analysis to ensure maximum network utilization within constraints, refine system operating plan as necessary

- Energy team – deliver the system operating plan in close to real-time, through dispatch operations covering: Power Balance, Reserve deployment / Frequency control, and Transmission constraint control

These functions are currently performed by various teams across different processes and data systems. In some cases, interactions across these processes are performed manually. Transmission analysis to evaluate near-term topology changes and update boundary constraints is performed by the transmission team and these limits are transferred into the dispatch system. Reserve scheduling and deployment is performed separately from power balance and transmission control.

Under the advanced dispatch optimizer system, power balance, transmission control and reserve deployment are all performed simultaneously in the security constrained economic dispatch module. Therefore, the development of transmission control instructions, reserve deployment instructions and power balance instructions will be automated through the integrated optimization system. As discussed in previous sections, there are two stages of dispatch optimization modules, the look ahead SCED which covers the period from 2 hours to 15 minutes ahead of real-time and RT SCED which covers real-time dispatch. Although these SCED processes are automated and integrated, there remains a need for highly trained and experienced operators to monitor and operate these systems. Key dispatch roles will remain as follows:

- Supervisor
- Transmission
- Scheduling / Reserve monitoring
- Power balance

The most significant difference in the roles under the advanced dispatch optimizer vision is that all the positions will utilize the same integrated tools but will have different displays and visualization tools that are customized to their individual functions. Another key difference is the primary function for the operators is narrowed to focus on monitoring the key scenario results, monitoring key near-term operational events (e.g., transmission line tripping, or generator tripping, etc.) interpreting the scenario impact and making key decisions through the decision support tools. One key advantage to the integrated system is when one operator position records a decision or enters information into the system, the information and impact are immediately visible to all other positions which streamlines communication and coordination. The automated adaptive input models and other automated processes perform data validation and monitor performance which allows operators to focus on monitoring scenario trends and making key decisions which improves situational awareness and gives operators more time to focus on key operational indices.

Currently teams of people are needed to fix data problems, identify missing information, and interpret data across siloed systems. The integrated technology and data platform and automated adaptive models will largely eliminate the need for this type of activity. These personnel will need to be retrained and deployed to monitor the automated systems, respond to error messages, and interpret analytical results from the performance management system. While the daily review of performance monitoring system results will be an automated process, it will require interpretation and identification of training opportunities for operational personnel. The operational support teams would likely possess the knowledge and skill sets to adapt to this role.

As the energy transition continues and the advance dispatch optimizer vision is implemented, distributed resources spread throughout the distribution systems will become more important resources to the grid operator. As the distribution system becomes more automated and digitally modeled, aggregated, and orchestrated distributed resources will routinely provide grid services. This will require enhanced coordination with distribution utilities, aggregators, and operators. The automated tools should allow each control room position to expand its function to include distribution coordination activities as necessary for their role. It is likely that the transmission operator role will need to significantly evolve to include even more distribution level coordination and communication.

9. Inhibitors and Challenges to Achieving the Vision

This section discusses potential inhibitors to achieving full development of the advanced dispatch optimizer system. The following three categories of inhibitors are discussed:

- Scale of problem and Pace of Transformation
- Stakeholder and User Acceptance of Transformational Changes
- Market Rules and Regulatory Codes.

The significant amount of historic information required to improve forecast accuracy and to develop adaptive machine learning models extends beyond just asset data and includes weather data, market data, system conditions, customer data, etc. The scope of data gathering and data correlation will be a significant effort that must be well managed through good data governance techniques to ensure all stakeholder have confidence in the data gathering process.

The rapid pace of the evolving energy transition requires transformational change to the processes and tools utilized to operate the power grid. The accelerating pace of the energy transition is driving the need for more rapid development and deployment of more advanced operational tools and processes. Development of the advanced dispatch optimizer system described in this report will be a large-scale project that requires collaboration with all stakeholders. Therefore, the sheer scale of the problem and the broad impact on all stakeholders creates significant risk to the project. An incremental approach and modular design are recommended to help mitigate to scale issues and create a more nimble, adaptable platform. Rapid prototyping and iterative development of key modules are recommended to speed development and mitigate deployment risk.

Power system operators will need time to develop confidence and trust in this type of new highly automated toolkit, therefore a potential inhibitor is operator acceptance. The rapid prototyping process will be beneficial in this area but will also need to be supported with extended training and testing cycles to allow operators to develop confidence in the tools.

The integrated technology and data platform and automated adaptive models will eliminate the need for teams to manually correct data and interpret data and information across siloed systems. These personnel will need to be retrained and redeployed to monitor the automated systems and interpret analytical results from the performance management system.

Rapid transformational change is difficult and stakeholder engagement and acceptance is critical to success. Incremental development and early engagement with stakeholders are recommended. Early engagement with distribution utilities will be important to encourage development of digital models of distribution systems. A potential inhibitor for distribution companies is the regulatory process to secure necessary funding for advanced modeling and automation.

Although the scope of this project did not include a comprehensive review of Market Rules and Regulatory codes, several key potential inhibitors were highlighted through the course of this engagement with various NGESO stakeholders. Potential inhibitors recommended for investigation are as follows:

- A key trend across many grid operators around the world is that they are placing higher value on resource flexibility and more emphasis on real-time market development to encourage and compensate flexible resources. This focus on valuing flexibility is viewed in many jurisdictions as critical to achieving the transition to cleaner, efficient, and affordable resources. In the current UK Market, rules that require NGESO to provide closed dispatch instructions (closed BOAs) for generators and pay them extra to alter their schedule appears inconsistent with the need to value flexibility and develop nimble and accurate real-time dispatch instructions. This market rule was developed over 20 years ago in a different era and is not utilized anywhere else in the world to our knowledge. The rule is inconsistent with efficient power grid operation and frustrates efforts to create efficient dispatch instructions and provide equitable treatment for all resources. As the transition continues, the UK system will increasingly need to depend on orchestrating thousands of small, distributed devices and incenting them to be reliably flexible. Continuing to guarantee large resources a prolonged and inflexible closed dispatch instruction will be problematic because it creates an asymmetry in the market which could disadvantage newer flexible resources. Additionally, the development of the advanced dispatch optimizer will be much more difficult using a closed BOA dispatch system because the approach of constraining the optimizer to meet the BOA requirements is inherently less optimal than a set point dispatch approach. As has already been observed in practice, this less optimal approach will continue to dramatically increase the cost of procuring system services like transmission control, reserves, frequency control and load following and will layer these increased costs presumably onto consumers. Therefore, a review of these market rules with consideration of the incentives for flexibility needed to support the energy transition, the equity issues and the significant cost issues is recommended.

- Another key trend across many grid operators around the world is to place higher value and, in fact more requirements, on all resources, including generators, demand response and alternative resources (e.g., batteries) to provide accurate offer information and accurate operational forecasts to the grid operator. Obviously, the entity in the best position to accurately forecast generation production is the generator owner and operator; however, it appears in the UK market there are not sufficient incentives to promote forecast accuracy. The market rules and regulatory requirements should be reviewed to ensure all generators are incented to provide accurate information and forecasts. As the energy transition continues reliable and affordable power system operation will also increasingly depend on balancing services from demand response and alternative resources so these resources should also be incented to provide accurate information.
- We understand that a nodal price-based market construct is consideration in the UK market. The advanced dispatch optimizer described in this report would be completely compatible with a nodal pricing system and its operational efficiency would likely be enhanced by such a market construct. The enhancement would be driven by the more granular locational price signals providing enhanced incentives for generation, demand response and alternative resources to respond to locational price signals in a manner consistent with actual conditions on the power system.