GE
Grid Solutions

Enhanced Frequency Control Capability (EFCC)

Optimisation Detailed Design

29/01/2016

NG-EFCC-SPEC-004_v1

imagination at work

Contents

Acronyms

Acronym	Description
CS	Central Supervisor
DSR	Demand Side Response
EFCC	Enhanced Frequency Control Capability
ICR	Indirectly Controlled Resource
LC	Local Controller
NG	National Grid
PMU	Phasor Measurement Unit
RA	Regional Aggregator
RoCoF	Rate-of-change-of-frequency
UoM	University of Manchester

1 Introduction

EFCC aims to correct the fast changing frequency (df/dt), caused by a mismatch of generation and load by deploying power resources in a quick and coordinated manner so as to ensure that the system remains both angular and frequency stable. There is the potential for a large number of resources to be involved in the response where optimisation will provide the important coordination role of the different resources, optimising for the overall response characteristic. The optimisation approach allows different technologies with various response characteristics to be incorporated and co-ordinated to arrest a frequency deviation, avoid over-response, and sustain the overall output.

Figure 1 shows simulated responses for three different scenarios, created using a test network; the first scenario has no EFCC control and therefore under-frequency load shedding thresholds are violated, the other two scenarios show EFCC responses where resources act immediately and where resources are delayed due to resource ramping characteristics. While both EFCC scenarios successfully arrest the frequency decay, the immediate response is better from a frequency perspective because it does not allow the frequency to fall as far. The aim of Optimisation is therefore to prioritise resources by how effectively they can arrest the frequency decay so that Resource Allocation (performed on the Local Controllers) can deploy them accordingly. The Local Controllers are responsible for the calculation of the required power response where the action is then performed locally due to the effects that latency could have on the response if the action was communicated from a central location.

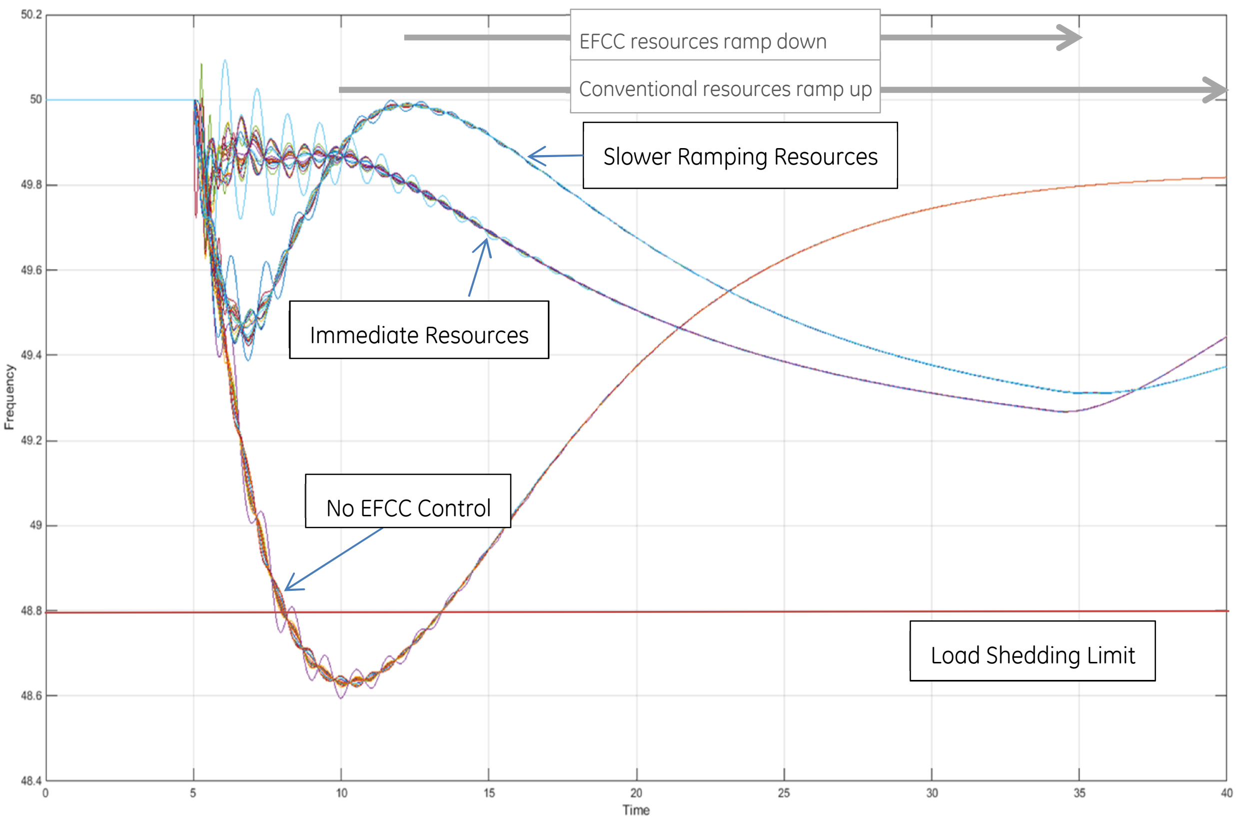


Figure 1: Varying frequency responses to an event due to different EFCC resource types.

This document deals explicitly with the Optimisation work package where details on event detection and resource allocation have been detailed in NG-EFCC-SPEC-001 and NG-EFCC-SPEC-003 respectively.

This document aims to define the context of the Optimisation problem within the scope of EFCC project, primarily in terms of the control scheme (online time domain) but also in a wider context of how this scheme may interface with 'business-as-usual' operations (offline time domain). The online optimisation is defined as that which uses live 'online' data from the control scheme such as live resource availability, available power etc. while the offline optimisation is related to contractual/market mechanism that defines the resources made available for real-time use. The online optimisation links the contractually available resources with real-time capability and prioritised deployment. The online optimisation is computed pre-event and event detection and resource allocation are applied during the event according to the optimisation results. The planning and offline optimisation are not prescribed in this document and can therefore consist of any function that falls outside of the online scope and can vary in time frame from hours to years.

The online optimisation provides a ranking of resources in each area, dependent on the speed of response and duration. The controller for each resource receives notification of the ranking. When a disturbance occurs, each controller will decide whether and how much of the resource to deploy, based on the ranking, severity and proximity of the disturbance, according to the Resource Allocation process.

In order to define this context, the next chapter defines an Optimisation framework which further describes the online and offline roles. The online optimisation is the focus of this document, and a detailed description of the relating physical architecture and functional processing are described. This is followed by chapter describing an operational example that quantifies how the optimisation algorithm works. Finally, a list of the results from testing relevant to the Central Supervisor and the Optimisation function are presented.

2 Optimisation Framework

In order for the EFCC scheme to effectively counter frequency disturbances from multiple independent contingencies, sufficient resource capacity should be made available through a market mechanism in long-term and operational planning, leading to resources being available for real-time arming and deployment.. Whilst the longer-term perspective is necessary for the mechanism to successfully operate, it does not need to be handled directly by the control scheme as these decisions are handled offline. This document therefore proposes a potential framework, shown in Figure 2, in order to segment the optimisation problem into various components that are characterised according to their respective time-scales. The aim of the framework is to make a clear distinction between the economic case and technical case to maximise interoperability with the future commercial arrangements. The market mechanism is not yet defined for EFCC, but it is recognised that it is necessary in order to supply the real-time system with the available resources that can be called on.

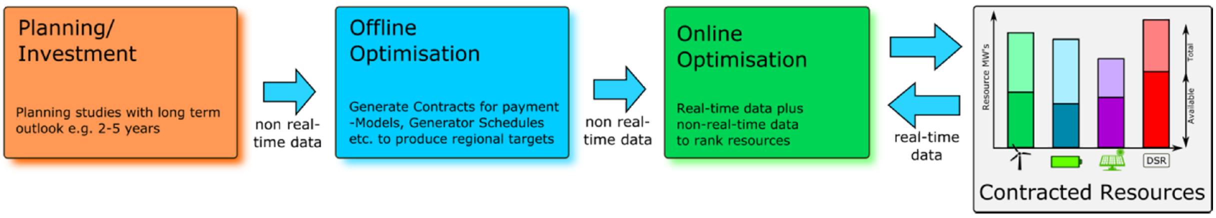


Figure 2: Optimisation stages and their interaction

The optimisation for EFCC is being proposed as a three stage process where the first two stages are carried out offline as a planning function, whilst the third stage is online/real-time and provides the near real-time optimisation. These stages are summarised briefly below.

2.1 Planning/investment stage

The role of this stage is to determine the amount and diversity of resources that are required per region based on the future requirements such as growing load, changing grid topology, interconnections and changing generation mix (and hence inertia). This will likely be determined using simulation packages and optimisation techniques and the output will relate to market incentives, i.e. target type and amount of resource per region per year of study. This stage lies in the role of the system operator and therefore not within the scope of the GE work package.

2.2 Offline optimisation stage (contracting stage)

When a resource has been built and is available for EFCC, it may not be optimal to use this resource based of the market philosophy used, particularly if there is an abundance of resources in a region. If the resources are contracted in a similar manner to existing reserves, the resource owners must be contracted some period before they are used in the system (i.e. day-ahead or seasonal). In the future when there may be an abundance of resources, it would be more economical to enable only the necessary resources. This, again, will likely be determined with a combination of simulation and optimisation techniques. This stage is not within the scope of the

GE work package; however it is suggested for further investigations and discussed in more detail in Appendix A.

2.3 Online optimisation stage

The final stage is the focus of the GE work package where its role is to select which resources would yield the optimal frequency response to an event. It is assumed that only the necessary resources are available (because of the previous two stages) and that resources are valued in terms of their service to the grid, rather than the provider's cost. Hence, there is no need for cost optimisation at this stage. However, certain types of resource may be preferable for resource providers; for example, battery resource can be deployed regularly, while demand disconnection has a greater impact on the resource provider, and therefore a mechanism is included that allows the user some control of the likelihood of deployment. The online optimisation will also accounts for the different time responses of the various resources.

The optimisation of all of these stages is based on the limited information thus far on market design; however the division of the optimisation into these stages is done in order to address the technical system requirements. The online optimisation uses real-time data and focuses on the technical constraints.

3 Online Optimisation (Central Supervisor)

The online optimisation application has been developed by GE for implementation on the Central Supervisor. It is based on real-time information from the scheme's resources and its objective is to determine the optimal mix of resources in order to deliver the best possible response profile and thereby slowing the RoCoF during events as effectively as possible.

The optimisation of resource deployment becomes necessary when the number of participants in the EFCC scheme becomes large – this is because the number of resources which tend to have a slower response will also increase leading to a large deficit in the initial response if the resources are deployed with equal priority. To demonstrate this, a number of resources with varying characteristics were modelled for illustration purposes. The response times do not necessarily reflect real-life performance. These are illustrated in Figure 3 where the total response of 15 different responses (top figure) shows a gradual increase initially, followed by a slow decay. The total power here is about 80 MWs. If the deployment of the resources is based on a proportion of this total value, e.g. 30% of total (24 MWs) (middle figure), the response shape will be similar, therefore leading to a slower initial response and delaying the halt in frequency decline. However, if the faster resources are prioritised for earlier deployment, it is possible to achieve the target value much earlier as shown in the bottom figure. The online optimisation focuses on the shape of this response.

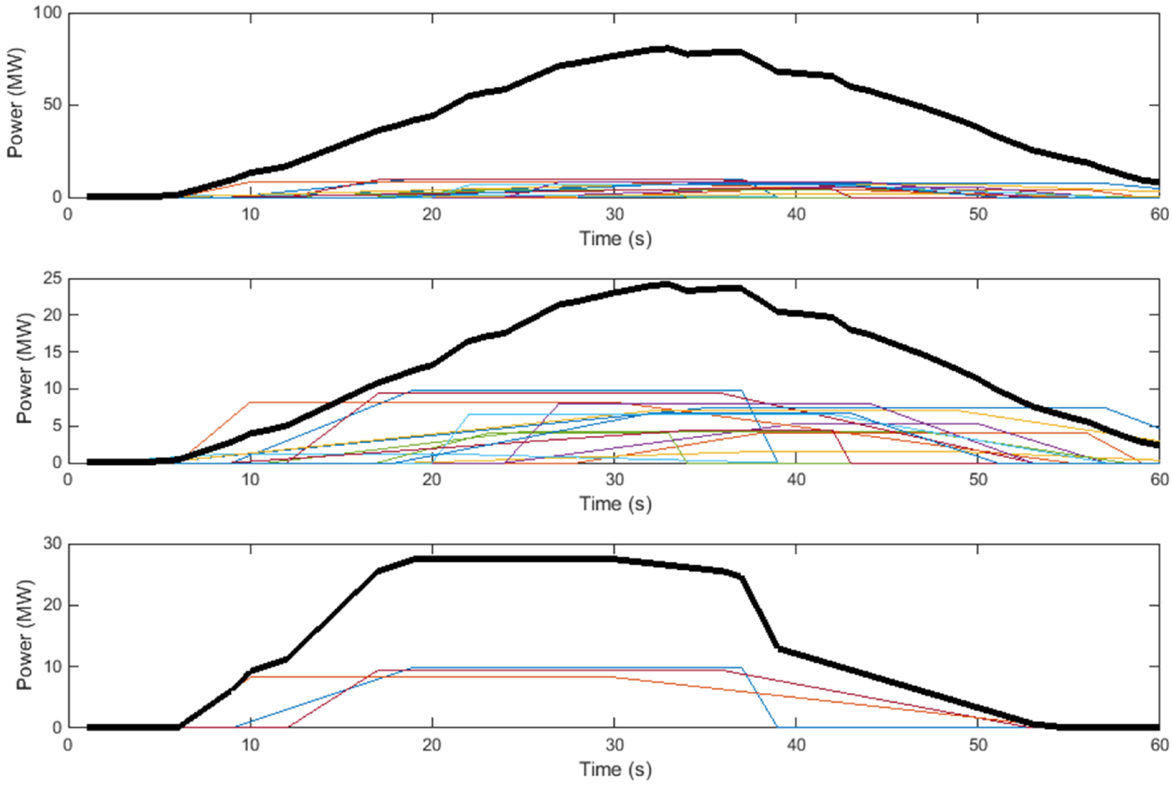


Figure 3: Typical response of 15 typical response types when, (top) all resources are deployed fully, (middle) all resources are deployed proportionally, (bottom) few fast resources are deployed fully.

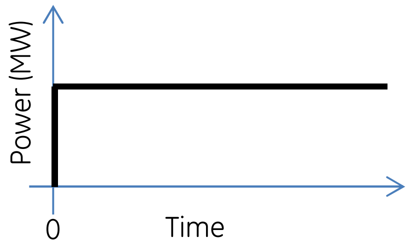
The ideal response from a region is one that can respond quickly to an event, but also sustain its response for long enough to allow a controlled response as it hands over to conventional governor control.

This is demonstrated by considering a simple example:

The ideal response is one that reduces the event's effect before the system degrades

- *Region A loses 500 MW of generation at time 0s*
- *If 500 MW of load is tripped in Region A at time 0s, the event impact becomes negligible*

Whilst the response suggested in the above example is obviously not possible, it provides a target by which to rank responses. The 'ideal' response is shown in Figure 4 and is characterised by an infinitely fast ramp (dP/dt) with no response delay and a sufficiently large power output that is sustained long enough to allow the primary response to react.



- 0 s time delay
- Infinite ramp rate
- Sustained response
- Magnitude equal to loss

Figure 4: Ideal response of a resource is a step response with 0 s delay, infinite ramp rate and a long sustained response

The objective of the optimisation algorithm is therefore to compare the resources against the 'ideal' response and then prioritise the resources in order to provide the best overall response.

4 Physical System Architecture

The physical system architecture is shown in Figure 5 and has been discussed in detail in previous documents; it is presented here in order to provide context to the details of the algorithm that is presented later. A point of particular importance is how the Central Supervisor (CS) communicates with the Local Controllers (LC) and Regional Aggregators (RA). The blue communication path (2) is used to communicate the optimisation results to the LCs. The CS also acts as a central point of scheme configuration where there is also a communication path to the RAs and LC for this purpose (grey dashed path 4).

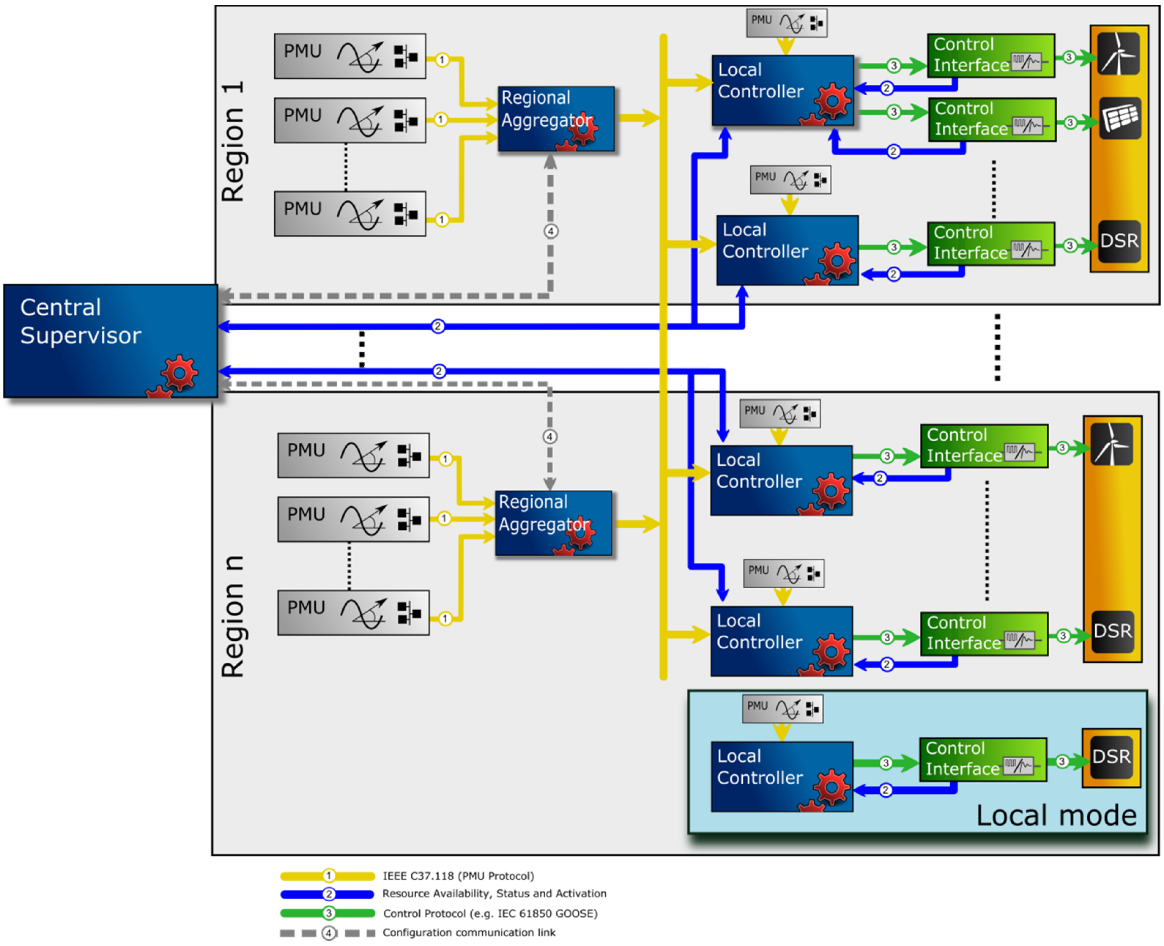


Figure 5: Physical system architecture

4.1 Central Supervisor System Architecture

The Central Supervisor requires certain inputs in order to perform its calculations which are then published (output) to the Local Controllers for their use during events. The inputs and outputs are defined and described in detail in the following sections.

4.1.1 Inputs

Figure 6 shows a schematic diagram of the input communication methods used by the Central Supervisor; each Local Controller sends specific information about the resource (Table 1) to the CS periodically and user input is used to define other required parameters which are described in Table 2.

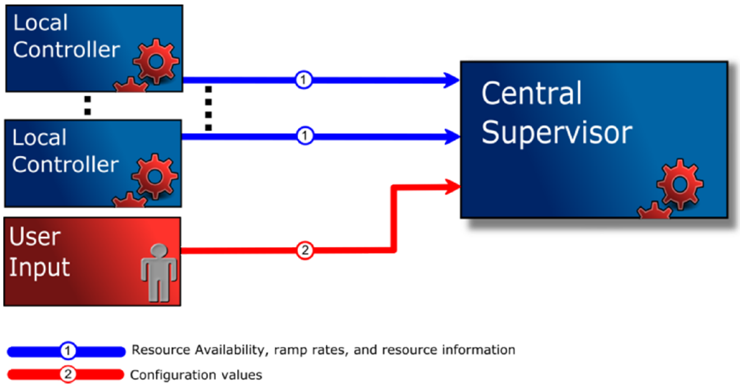


Figure 6: Schematic diagram of the Central Supervisor inputs

The Local Controller information includes the amount of resource available and its various ramp rates which define its performance. The response profiles are characterised in Figure 7 and the resource parameters are defined in more detail in Table 1. Table 1 also specifies the expected input values and suggested conditioning measures used for determining if the input is valid. The conditioning philosophy for these parameters would be either to use default parameters or to disable the resource, however it is most likely that a resource with incomplete data would best not be used due to the uncertainty this could cause.

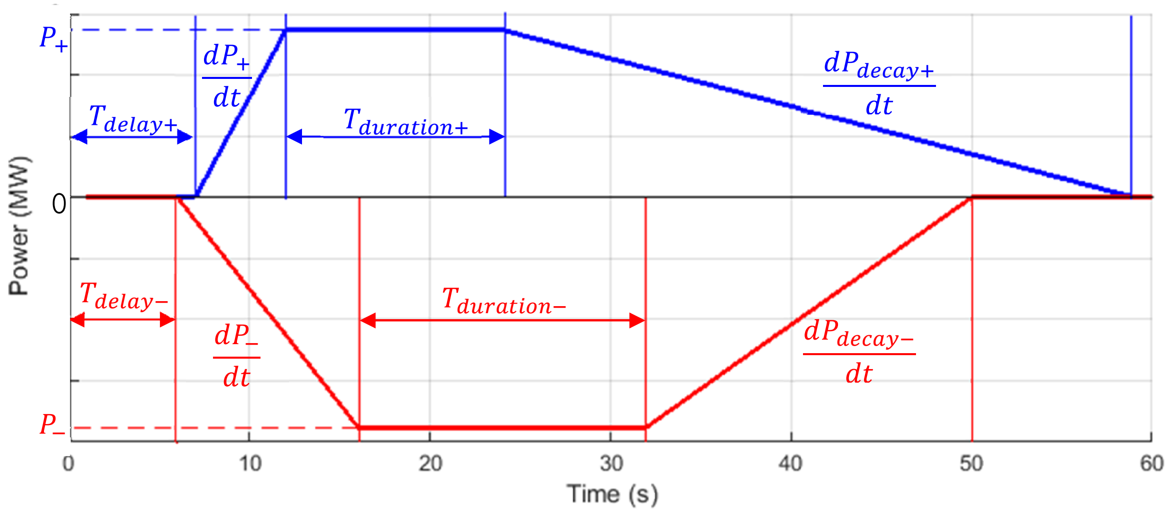


Figure 7 Diagram of the required parameters required to describe a resource response.

Table 1: Published information from each local controller

id	Symbol (As per Figure 7)	Description	Units	Qualification	Conditioning (if in error)
Type	n/a	Type of resource (Wind, battery etc.)	Enumeration	1. Wind 2. Battery/Solar 3. Load Bank 4. Switchable Load 5. Delayed resource	Disable resource
Availability	n/a	Is resource available?	Boolean	True: available False: unavailable	Set to False
Available Positive Response	P_+	Value of response available for under-frequency event	MW (or kW[1])	$0 \le P_+ \le P_{+max}$	Set to 0
Available Negative Response	P_-	Value of response available for over-frequency event	MW (or kW[1])	$0 \le P_- \le P_{-max}$	Set to 0
Positive-Response response time	T_{delay+}	Time delay before response	s	$0 \le T_+ \le T_{+max}$	Set to T_{+max}
Negative-Response response time	T_{delay-}	Time delay before response	s	$0 \le T_- \le T_{-max}$	Set to T_{-max}
Positive-Response response rate	$\frac{dP_+}{dt}$	Ramp rate of positive response	MW/s	$\frac{dP_+}{dt} > 0$	Disable resource
Negative-Response response rate	$\frac{dP_-}{dt}$	Ramp rate of negative response	MW/s	$\frac{dP_-}{dt} > 0$	Disable resource
Positive-Response max duration	$T_{duration+}$	Duration of sustained maximum output	s	$0 \le T_{duration+}$	Set to 0
Negative-Response max duration	$T_{duration-}$	Duration of sustained maximum output	s	$0 \le T_{duration-}$	Set to 0
Positive-Response decay rate[2]	$\frac{dP_{decay+}}{dt}$	Ramp rate of negative response decay period	MW/s	$\frac{dP_{decay+}}{dt} \ge 0$ If 0, then no decay	Set to 0
Negative-Response decay rate[2]	$\frac{dP_{decay-}}{dt}$	Ramp rate of positive response decay period	MW/s	$\frac{dP_{decay-}}{dt} \le 0$ If 0, then no decay	Set to 0

[1] This is not yet defined, but is most likely to be in MW unless the required accuracy of some small loads cannot be captured using the current data-type

[2] Whilst the decay rates are defined here, they are not used in the scheme at this point and could be omitted for simplicity

The user input is of upmost importance and some key calculation parameters are defined here. As shown in Table 2, the User Input data includes information required to complete the response calculation (i.e. system inertia), indirectly controlled resources (ICR) and other configuration information.

Table 2 lists these parameters and describes them in more detail. The user input would not have to be updated periodically but the algorithm should allow for this possibility, i.e. if an external automated process pushes this information periodically, the algorithm should be able to continue with the new parameters without interruption. The conditioning philosophy would be either to use default parameters or the last valid parameters.

As shown in Table 2, the User Input data includes information required to complete the response calculation (i.e. system inertia), indirectly controlled resources (ICR) and other configuration information.

Table 2: User input parameters

id	Description	Units	Qualification	Conditioning (if in error)
System inertia (H)	Estimated System inertia for the operating period	MW.s	$2H > 0$; $2H_{min} \leq 2H \leq 2H_{max}$	Set to default
Manual resource enable/disable	Matrix of enable/disable flags – mapped to IDs	Boolean	True/false per resource	Enable everything that is available
Required Positive Response per Region	The total positive power per region that is permitted to be deployed. This is required to limit deployment costs during events.	MW	$0 \leq P_{Required+}$	If 0 or $P_{Required+} < 0$, ignore this limitation.
Required Negative Response per Region	The total negative power per region that is permitted to be deployed. This is required to limit deployment costs during events.	MW	$0 \leq P_{Required-}$	If 0 or $P_{Required-} < 0$, ignore this limitation.
ICR Positive Response	Indirectly Controlled Resource influence per region (positive power only)	MW (or kW)	$0 \leq P_{ICR+}$	Set to 0
ICR Negative Response	Indirectly Controlled Resource influence per region (negative power only)	MW (or kW)	$0 \leq P_{ICR-}$	Set to 0
Configuration information	To be defined as scheme moves towards a product model	Various	TBD	Don't transmit settings

4.1.2 Outputs

The output communication channels of the Central Supervisor are shown graphically in Figure 8 - the optimisation results (blue path 2) are published to all Local Controllers. Additionally, specific configuration information (grey dashed path 2) is sent to all controllers in the scheme, i.e. LCs and RAs.

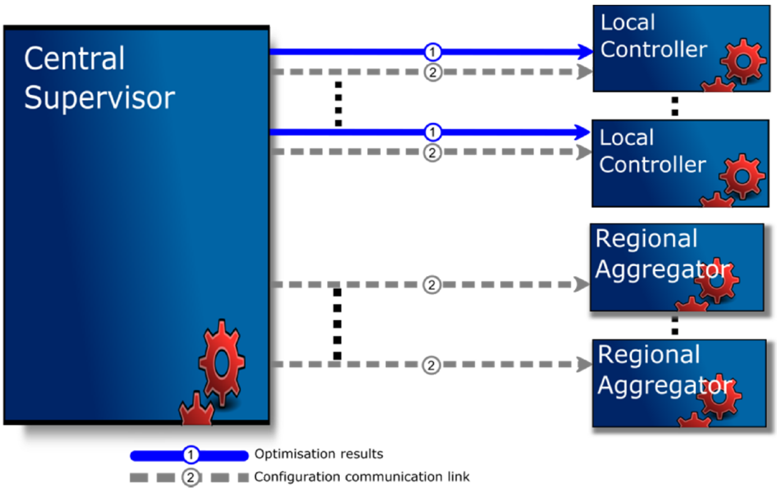


Figure 8: Central Supervisor outputs

In order for the resource allocation algorithm to work effectively several outputs are required from the Central Supervisor – these include the Optimisation results but information about other local controllers is also required and therefore transmitted. Tables 3 and 4 show how the optimisation results are output for continuous resources and discrete resources respectively. Table 5 shows the formatting of the message containing resource IDs, armed signals, and ranks (both negative and positive).

Table 3: Example format of the Optimisation output from the Central Supervisor for continuous resources

Regions	Rank: Best Rank 1	2	3	4	Worst Rank 5
1					
2					
3			P_{Total} MW Values		
4					
…					
n					

Table 4: Example format of the Optimisation output from the Central Supervisor for discrete resources

Regions	Discrete switchable loads (resources)				
	1	2	3	...	m
1					
2					
3			P_{load} MW, IDs		
4					
...					
n					

Table 5: Example format of the Central Supervisor output for armed signals and ranks

Resources	ID	Armed	Positive Rank	Negative Rank
1				
2				
3				
4				
...				
k				

The values of the ICRs per region will be sent to each of the LCs. In the deployment, many of the ICRs may operate with very similar mechanisms to EFCC and therefore can act alongside EFCC response. If the EFCC does not consider their parallel deployment, there is a risk of over-response; therefore, it is best to coordinate the two. A simple method to coordinate them is to assume that the existing ICR (whether hardwired or contracted) acts alongside EFCC and that EFCC will only deploy power over and above the ICR values specified, i.e. when deploying power, the total power from EFCC should be the difference between the regional requirement and ICR for each region.

5 Functional Processing

The Central Supervisor's processing is divided into smaller functional blocks and a summary of this is shown in Figure 9. At first all inputs must be conditioned to ensure they meet the minimum requirements; the conditioning is done as per the tables of Section 4.1.1. but can largely only be tested during the hardware implementation of the Central Supervisor. The Optimisation procedure performs the previously mentioned process of prioritising resources according to their response characteristics. The output of the Optimisation process is then formatted into a message that can be published to the Local Controllers.

The Central Supervisor is also used as a centralised platform to perform remote configuration of the field devices such as the regional aggregators and local controllers. This process does not form part of the scientific model but will be handled during the hardware implementation of the CS.

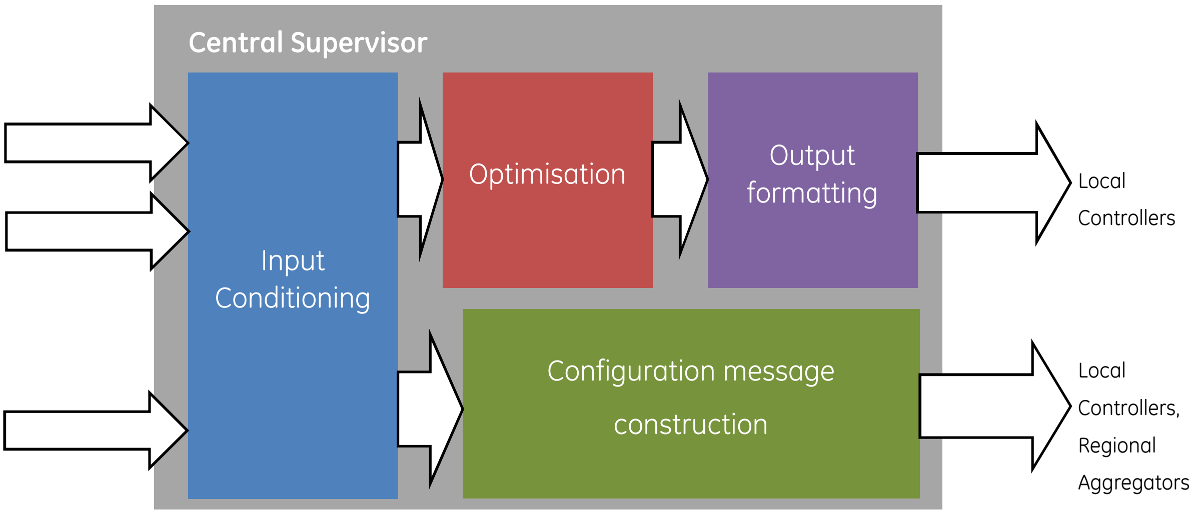


Figure 9: Function block diagram for the Central Supervisor process (Scientific model)

The procedure blocks shown in Figure 9 are described in more detail in the following sections.

5.1 Input conditioning

The input conditioning block ensures that the input from both the local controllers and the users is correct according to Table 1 and 2. The User Input data includes information required to complete the response calculation (i.e. system inertia) but also indirectly controlled resources (ICR) and configuration information. If any of the parameters do not meet the qualification limits, they will be corrected according to the conditioning column of these tables.

5.2 Optimisation

The Optimisation algorithm can be computed once all required information is available - the algorithm is triggered whenever any input data changes. The algorithm is also computed periodically to ensure local controllers are kept updated.

A simplified overview of the Optimisation algorithm is shown in the flow diagram of Figure 10 where the main functionality lies in comparison of the different response's time, rate and duration, thereafter the resources are sorted and formatted in order to present the results to the local controllers in a useful manner.

The aim of the optimisation algorithm is to present the resources to the LCs as a prioritised list based on the resources' ability to arrest frequency decay. A ranking system has been defined in order to classify this resource performance and simplify the publication of this information to the LCs. There are 5 ranks in total, Rank 1 represents the most effective resource (fastest with long duration) and Rank 5 represents the least effective resource (slowest with shorter duration). The optimisation algorithm assigns rank based on the resource response time, ramp rate and duration, however it is possible to manually assign a resource's rank if there is a desire to exclude particular resources from the optimisation algorithm – this is done via the user input into the CS.

Resource Allocation (handled by the LCs) will deploy resources according to rank, i.e. resources will be deployed from Rank 1 to Rank 5. This means that smaller events will be addressed by the lower ranks, e.g. Rank 1 and 2. Larger events would require more resources to be deployed and thus it would not be possible to achieve an 'ideal' type response because all resources in the region would be deployed. This is best explained with an example:

Assume there is 100 MW of response in a region made up from 10 resources. Assume that whilst the 10 resources are each 10 MW, they do not share the same response time, ramp rate or duration. The optimisation algorithm would rank the resources accordingly so let's assume the following result:

	Rank 1	*Rank 2*	*Rank 3*	*Rank 4*	*Rank 5*
Region A	*40 MW*	*10 MW*	*30 MW*	*10 MW*	*10 MW*

- *Now assume an event of 60 MW occurs in the region; Rank 1 and 2 would be deployed fully and 10 MW would be deployed proportionally from Rank 3.*

  This would result in the event deficit being met with the 'most effective'/fastest resources thereby arresting the frequency decay as best as possible

- *Assume that an event of 100 MW occurs in the region; resources from all of the ranks will be deployed. Whilst the response will not resemble the 'ideal' curve, this is the best possible response since no additional resources are available in the region.*

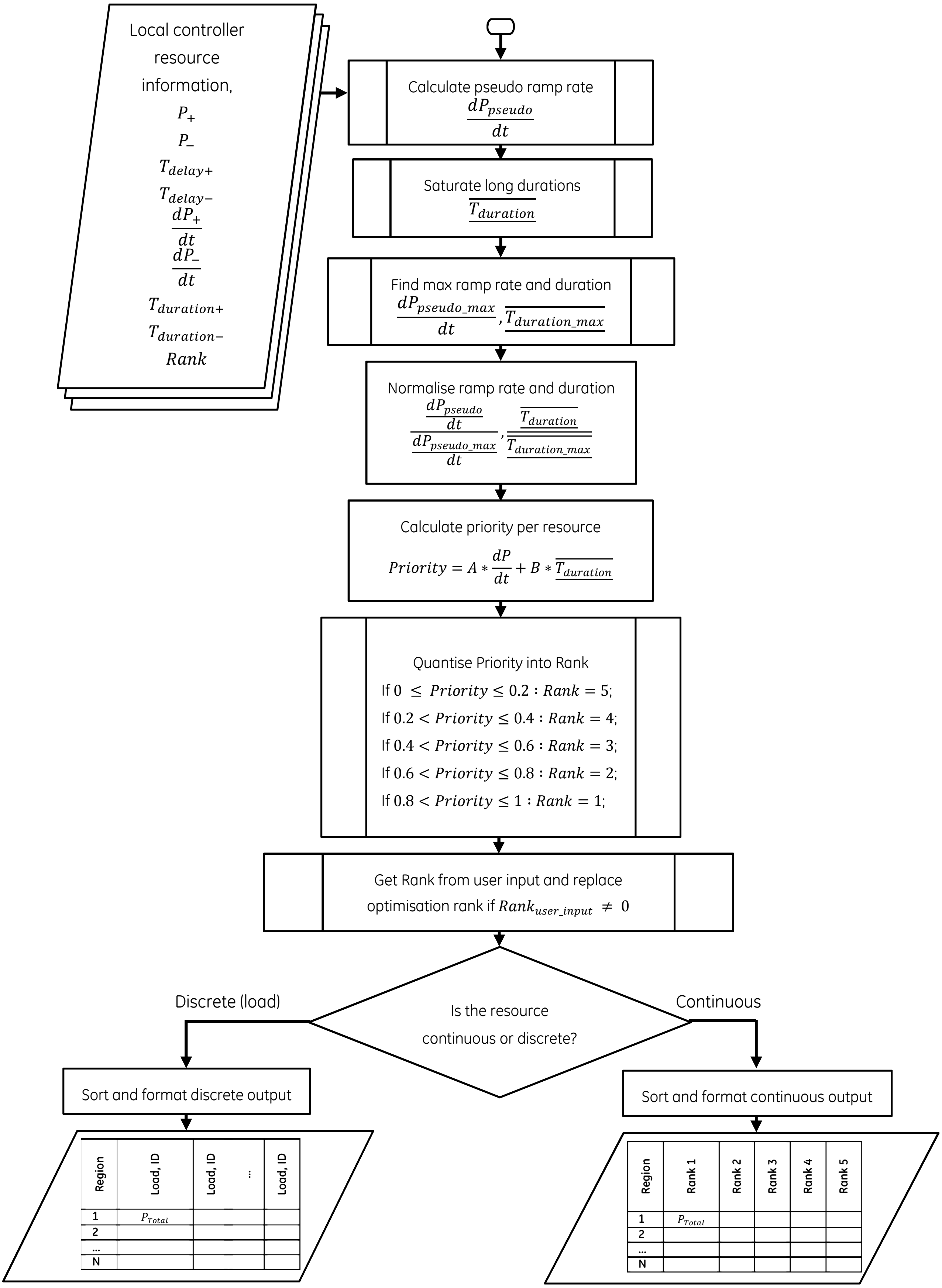


Figure 10: Flow diagram for the Optimisation procedure block

The subroutines of the flow diagram presented in Figure 10 are described in more detail in the following sections.

5.2.1 Calculate Pseudo Ramp Rate

It is difficult to directly compare resources in terms of response time and ramp rate therefore a pseudo ramp rate is calculated that takes into account both of these values to create a comparable metric for resource ranking. Figure 11 shows how the pseudo ramp rate is related to the true resource response that has a delayed ramp rate.

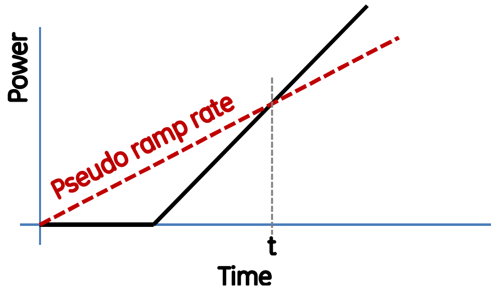


Figure 11: Pseudo ramp rate calculation from resource response rate and time

The following steps are used to calculate the pseudo ramp rate:

1. calculate the line equation for the existing ramp rate

$$y = mx + c$$

$$c = -m_{responseRate} * T_{delay}$$

2. using the above equation determine the y value at t seconds (1 s)

$$y_t = mt + c$$

3. calulate the pseudo ramp rate from the above value

$$m_{pseudo} = y_t/t$$

The t value used to calculate the pseudo ramp rate will be configurable but is currently set to be 1 s since this is considered to be in the 'Wide-area' control mode time frame of Resource Allocation.

5.2.2 Saturate Long Durations

A focus of the optimisation is to ensure that resources with poor sustain (duration) are ranked low – durations above a certain threshold should therefore be saturated to make their impact negligible when sorting the priorities. This parameter will be configurable but at this point is considered to be in the region of 10 – 20 s but should be linked with the conventional response time-frames.

5.2.3 Normalise Ramp Rate and Duration

The pseudo ramp rate and duration should be in per unit values to allow easier comparison – this is achieved by dividing each resource ramp rate and duration by the maximum of each metric respectively. The maximum values are calculated per region and therefore the normalisation is also specified per region.

5.2.4 Calculate Priority per Resource

The priority of each resource is calculated by calculating a weighted sum of the ramp rate and duration per unit values as per Equation (1). These weights (A and B) are configurable but in the example below the ramp rate is weighted by 0.7 and the duration by 0.3 in order to favour response speed over duration.

$$Priority = A * \overline{\frac{dP}{dt}} + B * \overline{T_{duration}} \quad (1)$$

As per Equation (2), the sum of A and B should be 1 in order to scale the priority factors correctly.

$$A + B = 1 \quad (2)$$

Adjusting the A and B coefficients will adjust how the optimisation is solved. For example, assigning a higher value to A increases the effect of the response speed and reduces the effect of the response duration. Similarly, reducing B to 0 will eliminate duration from the optimisation criteria. During scheme tests, these coefficients will be adjusted in order to determine suggested values.

5.2.5 Sort and Format Output

The outputs of the optimisation must be sorted and formatted as per the tables discussed in Section 4.1.2 so that they are in a format that is directly usable by the local controllers and optimised in terms of message bandwidth.

5.3 Output formatting

The output formatting block will take the results from the total optimisation procedure and compile them into a message that can be broadcast to all local controllers. It is important that the message is able to meet the constraints of the protocols used, i.e. IEC 61850, and the hardware platform.

6 Operational Example (Use-case)

An operational example is provided in this chapter since this best illustrates how Optimisation takes place and how it affects the overall power response. 20 artificial resources were generated with random assignment of their attributes (duration, ramp rate etc.) – these resources were used as inputs for this operational example and are shown in Table 6.

Table 6: Random resource information for 20 resources used as an operational example

id	positiveAvailablePower	negativeAvailablePower	resourceAvailability	resourceType	responseTimeForPositiveAvailablePower	responseTimeForNegativeAvailablePower	responseRateForPositiveAvailablePower	responseRateForNegativeAvailablePower	responseDurationForPositiveAvailablePower	responseDurationForNegativeAvailablePower	localRegionIndex	resourceRanking	normalisedPriority	optimisationRanking
1	23.2	39.6	1	3	0.5	1.0	3.5	2.8	45.4	59.7	5	0	0.301	1
2	5.1	30.4	1	1	0.5	0.7	2.9	2.7	54.1	32.4	3	0	0.3	1
3	80.1	14.3	1	1	0.3	0.2	2.4	1.3	22.1	39.7	1	0	1	1
4	32.7	88.0	1	1	0.8	0.6	2.4	2.0	10.8	58.1	3	0	0.162	2
5	87.7	78.5	1	2	0.6	0.9	2.3	4.1	53.9	25.8	2	0	0.644	2
6	37.7	0.0	1	4	0.5	0.5	1887.3	0.0	60.0	0.0	5	4	0.25	4
7	7.1	18.2	1	2	0.0	0.0	0.5	2.3	0.6	54.9	4	0	0.09	3
8	45.5	12.7	1	2	0.4	0.0	0.0	3.6	21.2	46.8	3	0	0.3	2
9	9.1	59.4	1	1	0.2	0.2	1.2	4.2	51.4	57.8	3	0	0.3	2
10	76.2	34.8	1	3	0.6	0.4	2.3	3.2	55.0	9.7	4	0	0.66	2
11	39.3	17.9	1	5	1.0	0.1	3.2	3.1	19.7	48.2	5	0	0.296	1
12	2.4	60.7	1	2	0.2	0.4	0.6	2.0	53.0	32.9	2	0	0.389	4
13	12.4	47.1	1	5	0.1	0.7	4.3	0.2	41.5	58.7	2	0	1	1
14	61.1	90.0	1	5	0.8	0.6	1.0	3.8	20.8	25.1	1	0	0.551	2
15	80.5	0.0	1	4	0.5	0.8	4025.6	0.0	60.0	0.0	5	1	1	1
16	83.1	0.0	1	4	0.6	0.9	4155.6	0.0	60.0	0.0	3	1	1	1
17	89.5	58.3	1	5	0.0	0.7	2.9	4.3	2.1	53.1	3	0	0.032	2
18	14.4	60.6	1	1	0.6	0.2	1.3	1.6	24.1	24.4	2	0	0.488	3
19	9.5	32.3	1	1	0.8	0.3	3.8	1.2	44.4	41.6	5	0	0.301	1
20	52.3	32.5	1	2	0.2	0.5	4.2	4.1	33.4	15.8	4	0	1	1

The Optimisation algorithm within the Simulink scientific model was executed in order produce the results shown in Tables 7, 8 and 9. Whilst discrete resources can be included in the optimisation algorithm, they are excluded here as an example of the manual override functionality. The discrete resources therefore fall under the rank manually assigned to each resource as shown in the 'resourceRanking' column of Table 6 – this assignment is propagated to the Optimisation output as shown in Table 8. The continuous resources are considered by the Optimisation algorithm and are ranked according to the speed and duration of their response – this is evident from the results in Table 9 that show slower resources being assigned worse rankings. For example, resource ID 12 from Table 6 has a ramp rate of only 0.6 MW/s and has therefore been assigned as the worst resource in Region 2 according to Table 9.

Table 7: Results from the Optimisation algorithm showing all positive available power including both discrete and continuous resources

Total Positive Available Power	**Rank**					
Region	**1**	**2**	**3**	**4**	**5**	**Total**
1	80.10	61.10				**141.20**
2	12.40	87.70	14.40	2.40		**116.90**
3	88.20	176.80				**265.00**
4	52.30	76.20	7.10			**135.60**
5	152.50			37.70		**190.20**
Grand Total	**385.50**	**401.80**	**21.50**	**40.10**	**0.00**	**848.90**

Table 8: Results from the Optimisation algorithm showing all positive available power showing only discrete resources

Discrete Positive Available Power	**Rank**					
Region	**1**	**2**	**3**	**4**	**5**	**Total**
1						
2						
3	83.10					83.10
4						
5	80.50			37.70		118.20
Grand Total	**163.60**	**0.00**	**0.00**	**37.70**	**0.00**	**201.30**

Table 9: Results from the Optimisation algorithm showing all positive available power showing only continuous resources

Continuous Positive Available Power	**Rank**					
Region	**1**	**2**	**3**	**4**	**5**	**Total**
1	80.10	61.10				**141.2**
2	12.40	87.70	14.40	2.40		**116.9**
3	5.10	176.80				**181.9**
4	52.30	76.20	7.10			**135.6**
5	72.00					**72**
Grand Total	**221.90**	**401.80**	**21.50**	**2.40**	**0.00**	**647.60**

Further to the results shown in Tables 7, 8 and 9, the effect of Optimisation on the overall resource response can be seen in Figure 12. Here the charts on the left show the total response per region when all of the resources are used; without Optimisation the resources would all have equal priority and would be deployed proportionally to the overall response resulting in a slower initial response rate. The charts on the right of Figure 12, however, show that if a smaller response is required and only Rank 1 is deployed, a faster ramp rate would be achieved. The responses on the right tend to be more like the 'ideal square wave' thus proving the Optimisation algorithm to be effective. Recall that the aim is to arrest a frequency excursion as quickly as possible, therefore deploying resources which reach the target value the fastest will have the most effect at arresting this excursion.

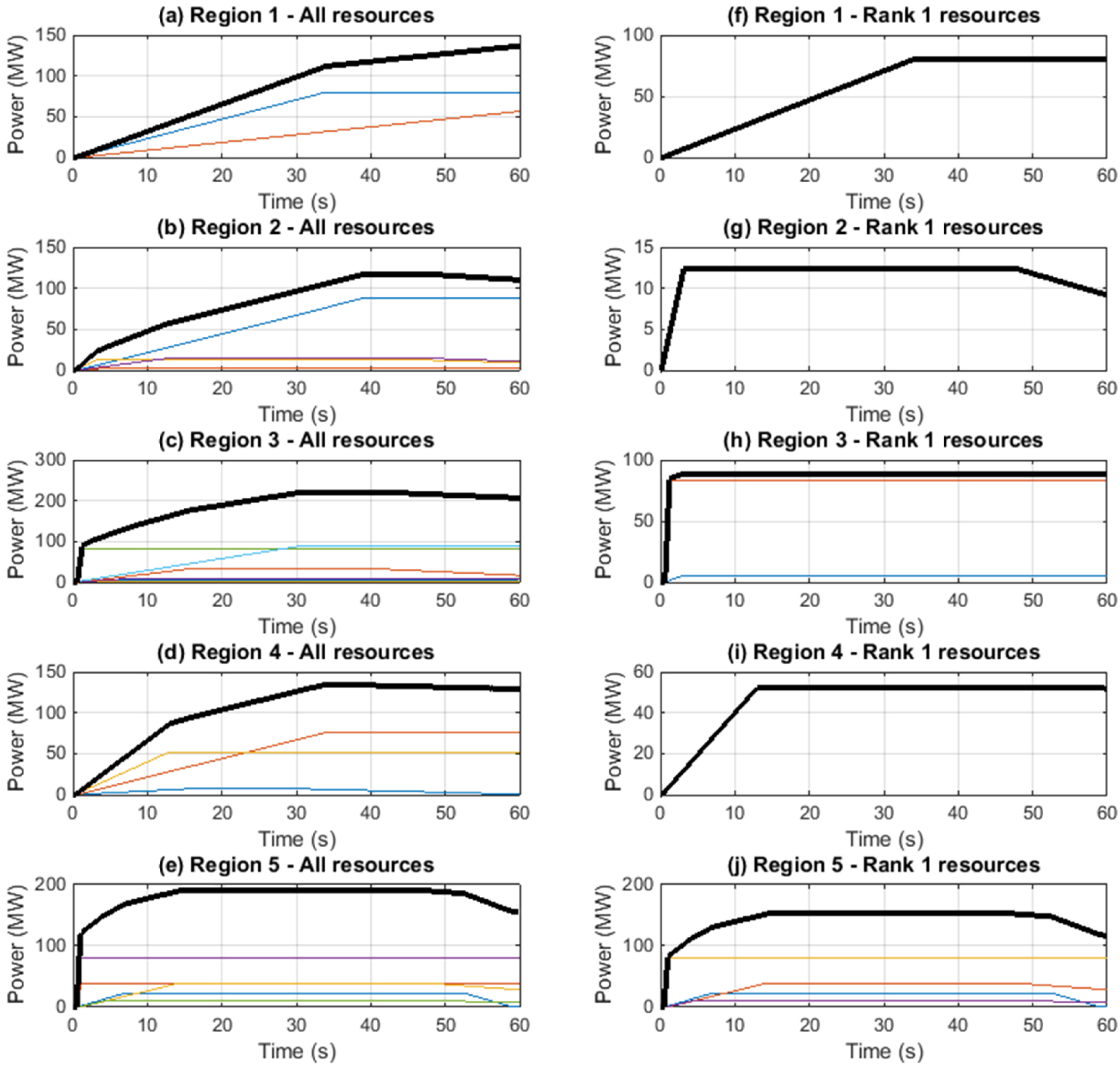


Figure 12: Examples of resource responses when deploying all resources (left) and only resources from rank 1 (right)

7 Test Summary

The sections below list the tests from the resource allocation design document that are related to the optimisation. The scientific model tests have been done and listed accordingly. Tests results have been marked as 'hardware' where further tests are required during hardware implementation of the CS or EFCC scheme.

7.1 Resource Allocation Tests

Table 10: Resource Allocation Test Summary

Function	Requirement	Test #	Test Description	Result
Initialise control scheme	Upon start-up, or a significant change, system must reinitialize itself	RA101	The closed-loop Simulink model will be linked to PSAT and the resource information supplied from PSAT. The CS in the model will receive data from the PSAT and should update the LCs in the model accordingly.	Pass
Collect information from LCs	Upon querying LCs, CS must wait for sufficient period to receive data	RA201	This will be a PDC/PLC test and cannot be tested in Simulink model. Await Hardware development	Hardware
Ability to update upon status change	CS resource allocator shall decide if a received update change is significant to redispatch resource	RA401	When the CS receives updates from the LCs on a resource change, the CS will determine if the change is significant. The CS Simulink block will monitor the signal from the LC for changes in Available power or availability.	Pass
Optimisation	CS must find an optimal mix of resources for given set of conditions	RA601	This has been developed and discussed throughout this document. The operational example in Section 6 forms a significant part of this test.	Pass
Account for indirect frequency response resource	e.g. services from Flexitricity, CS should be aware of what is available and where and how to compensate	RA801	The regional requirement values are calculated and forwarded to the LC, however Resource Allocation is responsible for this limitation taking effect – this will therefore be tested during the scheme tests.	Pass Retest in scheme

Manual input for local resources	It should be possible to manually enter details of resources into CS (e.g. local resources, relay tripped resources, …; Compatibility with parallel protection)	RA901	The inputs are available in the scientific model but the test becomes valuable when the user interface is better defined – the testing will therefore be delayed until the CS is productised.	**Hardware**
Detection of a failover	CS should detect loss of a LC and adjust its network model accordingly	RA1101	If the CS loses one of its LCs, the availability will go to zero. This is accounted for by rerunning the overall dispatch and update the regional breakdown information which is sent to each of the controllers. When an LC is lost, its power availability will be 0, however its detection will be determined from the protocol used which is still in development. Therefore, for this test, the availability of the controller is switched to unavailable at the resource to validate the updating of the CS. An LC in region 3 becomes unavailable after 3s at which point the CS should update to reflect the change	**Pass**
Use a robust method for transferring data between CS and LCs	Should use a reliable communications link and a protocol based on TCP between CS and LCs	RA1201	This will be developed and tested on the Hardware LC and not in the simulation environment. It will therefore be tested in the later stages.	**Hardware**
Data Preparation	LC must be able to take local measurements and package them in suitable format for CS. CS must package optimisation and dispatch results in suitable format for LCs to decipher. IEC61850 represents a possible standard for realizing such a data exchange.	RA1301	This will be the interface between the Control model and the Controller hardware software and will be included in the hardware test phase. .	**Hardware**

Flexible objectives	Resource allocation must be capable of accepting manual user input to define the optimisation objective functions, i.e. the national grid resource reserve.	RA1401	As mentioned in the sections of this document, the optimisation process is configurable by assigning discrete rankings, weighting factors for the priority calculation and variations on the pseudo ramp calculation. These variables are currently inputs to the scientific model but must be retested in a product and scheme context.	Pass
Data publishing	CS must be capable of publishing messages to the LCs in the field which may contain look-up tables. This may be a generic multicast message to all LCs, or individual messages to each LC.	RA1501	The Control model creates data in suitable format which is then to be published using the suitable protocol. The test will be further clarified in the hardware test phase.	Pass
Data exchange from LC to CS	Data transmitted from LC to CS is, but not limited to, the following: • Resource availability • Available Power (+/-) • Response Time • Duration of response • Response type	RA1701	The LC sends the appropriate data to the CS that is required for allocation and optimisation purposes. This however should be retested during the hardware phase.	Pass
Data exchange from CS to LC	Data transmitted from CS to LC is, but not limited to, the following: • Arm/disarm • Configuration data • Regional Resource breakdown	RA1801	The CS output data has been well defined in this document. The scientific model is currently able to send all of this information but this will be retested during hardware and scheme tests.	Pass

7.2 Control Initiation Tests

Table 11: control Initiation Test Summary

Function	Component	Test #	Test Description	Result
Manual Inertia value and other configuration data	Inertia is used for the response calculation, this is defined at CS level and communicated downstream to all LCs. Must be possible to manually enter this value, and other configuration data such as max RoCoF at CS level.	RA2001	The value is configured at the CS and then sent to each of the LCs to verify the propagation of data from the CS to the LCs.	Pass
Account for indirectly controlled load	Local PhCs or relays in a region may deploy resource in parallel to the scheme. For best accuracy, the control should be aware of the presence of such resources.	RA2301	The ICRs value per region is subtracted from the total power requirement per region and forwarded to each LC. The LC's inherently take these values into consideration based on this action. This will be retested in more detail during scheme tests.	Pass Retest in scheme

8 Conclusion

This document provides the context for Optimisation both within the EFCC scheme and the larger context of integration of this control scheme into an operational product within National Grid's existing and future business models. The online optimisation algorithm, which refers particularly to the context of the EFCC scheme, is described in detail. The Central Supervisor device, which houses the optimisation algorithms and other centralised configuration services, is defined on a high level including an in-depth description of its inputs and outputs. An operational example using randomly generated resource values and the existing Simulink scientific model is presented and proves that the optimisation is effective at prioritising resources with faster responses and acceptable durations. The test results are summarised in the form of a table.

Appendix A. Planning and Offline Optimisation

Offline optimisation as described in this appendix includes all the stages not related to the online optimisation; therefore both the planning/investment stage and contracting stage are described here.

A.1. Planning/Investment Stage

The planning/investment stage is intended to provide mid to long-term sustainability of the scheme; for example, 5-year planning on future inertia levels to determine the future EFCC resource requirement. Additionally, the types of events for which EFCC should act in the future should be analysed, such as potential outages, large loss events, etc. This stage will be performed offline, based on suitable network models, and investment studies, etc. to ensure that there will be sufficient resource to cover the future frequency events.

A.1.1. Outputs

The output of this stage should be a list of recommended resources per region looking into the future. This list should feed into existing investment/incentive processes to ensure the resources are made available before the system inertia degrades. This stage should take the following into account:

- Resource characteristics
- Cost
- Region
- Forecasting Inertia degradation
- Seasonal requirement variations
- Changes in RoCoF due to regional inertia

A.2. Offline Optimisation Stage (Economic/Contracting Stage)

The Contracting stage considers a shorter term outlook, e.g. the current season, month, etc. This stage will be based on the market mechanism and will tie into the contract payments made to resources for supplying EFCC resource. It is being assumed here that the resources will be contracted for a period of time in which they should be available for EFCC response regardless of whether an event occurs and they are deployed or not.

As the demand on the grid changes over the day, the generation will change accordingly to meet that demand. The make-up of the generation can vary over the course of a day too, meaning there are different inertia levels over the day depending on what plant is generating. Additionally, the worst case contingency may be different depending on the generation schedule, so NG may opt to have more rapid frequency response contracted depending on the worst case loss of generation. Whether these situations are assessed under a day-ahead schedule, monthly, or seasonal etc. should be defined in future work.

The loading, generating and outage scenarios can be determined offline using suitable models and studies and should tie in with NG's plans for demand forecasts and generation day-ahead schedules, etc. The aim of this stage is primarily to quantify the amount of EFCC resource that should be contracted in order to meet a resource requirement value, i.e. which of the resources from the superset generated in the planning/investment stage should be contracted for payment. The resource requirement should be related to the worst case contingencies in the regions, balanced by some risk and cost factors. The analysis should be performed on a regional basis in order to provide a required resource volume and a contracted resource volume for each region. The sum of the regional requirements forms the total system requirement.

The total system requirement should not simply be the worst case loss of generation in the system. If the system total was defined according to the worst case generation loss, it would mean that in the event of that loss, all the resources in the system would need to act. It would not then be possible to target the required action closest to the event as the regions close to the event are insufficient to meet the loss entirely. On the other hand, if there is sufficient fast-acting reserve within an area such that the network stability is not degraded, then slower reserves outside the area can complement the overall response to achieve a system balance. Therefore, the requirements should be defined such that there is sufficient fast-response capability in each area to avoid degrading stability, and an overall total that would probably lie between the single largest contingency and the sum total of the largest contingencies of the areas. However, the actual volume of response to target is not yet defined.

Depending on the chosen forecast scheduling, some of the resources that are contracted may not be available when they are called upon, e.g. if a day ahead schedule is used and a wind resource is called upon to provide response when there is no wind. To account for this, there should be a suitable mechanism by which to account for the risk or assumed availability of that resource in the total contract. In a region with a particularly high penetration of intermittent resource, the assumed availability for those resources may need to be lower hence requiring a higher contracted power value in order to decrease the risk of not meeting the required power.

A.2.1. Outputs

The output from this stage should be a set of contracted resources which provides the best economical and technical balance in order to achieve the total contracted resource power value ($\mathrm{P_{contract}}$) and the total actual power ($\mathrm{P_{required}}$), which is based on the worst event per region. The output should be as follows per region:

Table 12 Proposed output from offline optimisation

Resource ID	Region	Contracted Power	Contracted?	Comment
1	1	10	✓	Contracted
2	1	20	✓	Contracted
3	1	15	×	Ignore
4	1	8	×	Ignore
5	1	6	×	Ignore
6	1	4	✓	Contracted
7	1	2	✓	Contracted
$\boldsymbol{Region\ k\ P_{contract}}$		***36***		
$\boldsymbol{Region\ k\ P_{required}}$		***25***		

Note:

- Only resources that have been contracted before an event will be utilised by the EFCC scheme.
- Only the contracted resources would be reimbursed for their EFCC response during this period whether or not the response is required. This therefore assumes a pre-emptive market structure where resources are contracted using forecasted values and penalised if proven to not respond when required.