European Commission | Horizon 2020 European Union funding for Research & Innovation

# Assessment of the Technical Reliability Performance of EU-SysFlex Solutions

D10.3

EU-SysFlex



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773505.

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|---|---|
| **PROGRAMME** | H2020 COMPETITIVE LOW CARBON ENERGY 2017-2-SMART-GRIDS |
| **GRANT AGREEMENT NUMBER** | 773505 |
| **PROJECT ACRONYM** | EU-SYSFLEX |
| **DOCUMENT** | **D10.3** |
| **TYPE (DISTRIBUTION LEVEL)** | ☒ Public<br>☐ Confidential<br>☐ Restricted |
| **DUE DELIVERY DATE** | July 2021 |
| **DATE OF DELIVERY** | 19/11/2021 |
| **STATUS AND VERSION** | |
| **NUMBER OF PAGES** | 42 |
| **Work Package / TASK RELATED** | WP10/T10.1.3 |
| **Work Package / TASK RESPONSIBLE** | R. Soler (EDF) / D. Pudjianto (Imperial College London) |
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# DOCUMENT HISTORY

| VERS | ISSUE DATE | CONTENT AND CHANGES |
|---|---|---|
| 1 | 01/07/2021 | The first version edited |
| 2 | 27/09/2021 | Updated to address all comments and feedback from the reviewers |
| 3 | 09/11/2021 | Updated based on the feedback from PMB |
| 4 | 19/11/2021 | Validated by the PMB |

# DOCUMENT APPROVERS

| PARTNER | APPROVER |
|---|---|
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| EIRGRID | John Lowry (Project Coordinator), upon PMB review |

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AB | Advisory Board |
| CA | Consortium Agreement |
| COPT | Capacity Outage Probability Table |
| DoA | Description of Action |
| DB | Demonstration Board |
| DER | Distributed Energy Resources |
| DSO | Distribution System Operator |
| EC | European Commission |
| EC-GA | Grant Agreement |
| EENS | Expected Energy Not Supplied |
| EFBC | Equivalent Firm Balancing Capacity |
| ELCC | Effective Load Carrying Capability |
| ES | Energy Storage |
| ESDC | Equivalent Service Delivering Capacity |
| EU-SYSFLEX | Pan-European System with efficient, coordinated use of flexibilities for the integration of a large share of Renewable Energy Sources (RES) |
| GA | General Assembly |
| MO | Management Office |
| PC | Project Coordinator |
| PMB | Project Management Board |
| RES | Renewable Energy Sources |
| TM | Technical Manager |
| TSO | Transmission System Operator |
| WP | Work Package |

# EXECUTIVE SUMMARY

The EU-SysFlex project investigates innovative solutions to provide operational flexibility and grid ancillary services to deal with the increased penetration of variable renewable (RES) generation in future. New flexibility resources, primarily from distributed small-scale devices, are likely not to have the same reliability as traditional solutions. Small-scale resources, such as demand response from electric vehicles or electric heating loads, are not purely dedicated to providing grid services; therefore, their availability will be temporal. The reliability of some other technologies, such as storage, to provide grid services also depend on their energy storage capacity. In addition, most of the EU-SysFlex solutions are from devices connected to the distribution grid. Therefore, the delivery of their services to transmission depends on the strength of the local distribution networks and good coordination and interfaces between the Transmission and Distribution System Operators.

Ignoring lower-reliability resources will trigger investment in traditional solutions that provide reliable grid services at a higher cost. The system operator needs to understand the equivalent capacity from the new resources against the traditional capacity as a reference to use the new resources. Even if the reliability of the new resources may be low, extra capacity can be procured to maintain the same level of reliability if needed. In this context, this report provides the benchmarking methodologies to quantify the reliability performance of new EU-SysFlex solutions and derive the equivalent service delivering capacity from flexibility resources without compromising the overall service reliability. A range of illustrative cases is provided to demonstrate the impact of sensitive factors that influence the equivalent capacity, e.g. availability factor, interdependency across service providers, network reliability, and energy storage capacity.

The studies demonstrate that the equivalent capacity from distributed resources depends on many factors:

- Temporal availability of the resources – the equivalent capacity becomes higher if the availability of the resources can be improved.
- The number of Distributed Energy Resources (DER) units – a higher number of DER units will increase diversity and capacity contribution. Furthermore, flexibilities proliferation will compensate for the individual unit failure.
- Desired confidence level – the higher the number, the lower the capacity contribution can be relied on by the system operator. It will require a trade-off between the cost and reliability performance of the DER services. Allowing low-cost but less reliable DER services may reduce the system costs, although the system operator may need to purchase more services to deal with the less reliable providers. This aspect may require further investigation in future to analyse the costs and benefits of using that approach.
- Local network constraints might limit DER operation affecting the maximum volume of DER services offered and used by a transmission system operator.
- Common-mode events – these events drive a uniform or identical response from DER units reducing their diversity and reliability performance. For example, extreme cold or hot weather conditions may substantially reduce smart heating or cooling systems' availability to support the electricity grid.
- Storage capacity – a higher storage capacity enables DER to provide services for a longer period if needed. DER contribution also depends on the duration of the service required.

By understanding the individual or aggregated reliability performance of DER, the system operator can therefore manage the risk and determine the optimal portfolio of resources considering both conventional and DER. Further work will be required to understand the costs and benefits of using DER flexibility and

parameterise their reliability. The latter will require trials with a sufficient duration across a full range of plausible operating conditions that can drive different reliability performances.

# 1. INTRODUCTION

## 1.1 CONTEXT

The EU-SysFlex project investigates innovative solutions to provide operational flexibility and grid ancillary services to deal with the increased penetration of variable renewable (RES) generation in future. While the project is tested against the 2030 target with 50% renewable penetration, the solutions are expected to be scalable and suitable for the more ambitious net-zero emissions energy systems in 2050. The latter will involve a higher renewable energy penetration; it is expected to supply about 80% of the demand while the remainder will be supplied by nuclear and other dispatchable low-carbon technologies such as gas-fired power plants with carbon capture and storage.

In contrast to the present system that relies primarily on large-scale dispatchable generators to balance electricity demand and supply and provide grid services for system security, the future system will require alternative sources considering the significant reduction in the energy production of conventional dispatchable generators and their operating hours. In this context, the EU-SysFlex project has demonstrated the suitability of electricity storage applications, demand response technologies such as smart electric vehicle (EV) charging systems, smart heating, ventilation and air conditioning (HVAC) systems, and distributed generation and flexibility technologies to provide system services supplementing the flexibility from transmission connected plants.

However, the use of new resources, particularly from small and medium-scale distributed technologies, attracts questions on the reliability of those new service providers compared to traditional providers due to several reasons:

- The availability of the resources may vary substantially across time since providing grid services may not be the main objective of the new providers, and, e.g. the availability of EV depends on the user's need for transport rather than to support the electricity system. Only when the EV is stationary and connected to the grid, it can provide system services if needed. Another example is a smart HVAC system; its availability tends to be less when the ambient temperature is very cold or hot as the end-user needs the HVAC system to control the temperature.
- The ability to deliver grid services to a transmission system from the new resources might be affected by constraints at distribution systems. Harnessing flexibility from distributed resources may require more robust distribution network capacity and coordination between transmission system operators (TSOs) and distribution system operators (DSOs).
- Most distributed resources are small scale, and to achieve a meaningful volume for transmission grid services, they need to be aggregated and controlled. However, there is a lack of understanding about the reliability performance of the aggregated resources.

As the availability of most small-scale distributed flexibility resources varies in time, especially demand response technologies and small-scale energy storage, the reliability of such individual resources is likely not to be as high as the reliability of traditional grid service providers. However, ignoring distributed flexibility resources with less reliability means that the capacity of traditional resources may need to be maintained at a higher cost and limit the volume of renewables that can be integrated. For example, out-of-merit thermal plants need to operate at or above their minimum stable generation limit to provide grid services; consequently, their energy production becomes a barrier for low-cost and low-carbon resources.

Furthermore, facilitating market access to distributed flexibility resources will increase grid service providers, improve market competition, and encourage technological innovation in providing more cost-effective grid services. Finally, as the resources are spread across the system, this distributed nature will benefit local and national energy system needs. Therefore, understanding the reliability of distributed flexibility resources such as those investigated in the EU-SysFlex project is crucial to building confidence and informing system operators to devise appropriate strategies to utilise those resources efficiently to secure system operation.

## 1.2 RELATION TO OTHER WORK PACKAGES

Figure 1.1 provides an overview of different demonstration programmes in EU-SysFlex investigating the applications of various technologies such as energy storage, demand response or flexible load technologies and distributed generation to provide grid services.

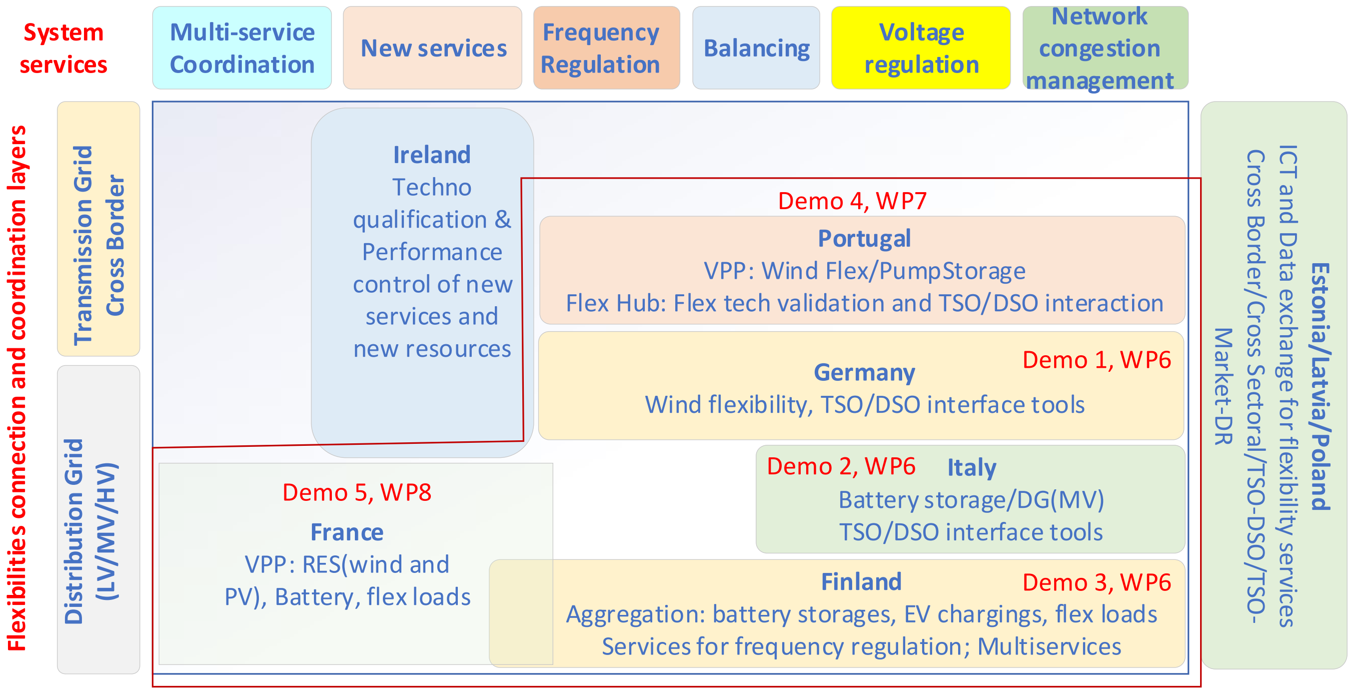


FIGURE 1.1 OVERVIEW OF SYSFLEX SOLUTIONS INVESTIGATED IN DIFFERENT DEMONSTRATION PROGRAMMES

Therefore, the studies described in this report will focus on distributed generation, storage, and demand response to provide network security services, balancing, and contribution to supply security. While the studies are not applied directly to the trials, the aims are to provide some insight and approaches that support reliability evaluation for future trials.

## 1.3 OBJECTIVES AND SCOPE OF THE WORK

The key challenge addressed in this report is associated with the fact that the new EU-SysFlex distributed services may not have the same reliability characteristics as traditional solutions. However, this shortcoming can be countered with purchasing a higher volume of flexibility capacity as long as system operators can calculate the equivalent capacity and the resources can provide grid services at lower costs. Therefore, the general objective of the work is to provide benchmarking methodologies to quantify the reliability performance of new EU-SysFlex solutions and derive the equivalent capacity so they can be compared with the capacity of the traditional service provider without compromising the overall service reliability. More specifically, the work also aims to:

- Assess the risks associated with the delivery of novel distributed energy resources providing flexibility
- Understand the drivers of the reliability performance and the possible common-mode events that affect the reliability of novel services
- Quantify the ability to deliver services at various aggregation levels and deployment scales
- Establish a framework to enable a level playing field between traditional solutions and distributed energy resources for providing grid services

The work focuses on the technologies investigated in EU-SysFlex, mainly:

- Distributed generation
- Distributed storage
- End-use demand-side response

Those technologies will be used to provide the following system services:

- Network security
- System balancing
- Supply security

It is worth noting that while the studies demonstrate the comparison between the reliability of new services compared to traditional ones, determining the optimal portfolio for flexibility services is not in the scope of this report.

## 1.4 REPORT OUTLINE

The remainder of this report is outlined as follows.

- Chapter 2 provides the general approaches and numerical methodologies to derive the Equivalent Service Delivering Capacity (ESDC) of the new solutions considering a range of factors that may affect the reliability performance of those solutions under investigation.
- Chapter 3 discusses the results of case studies demonstrating the applications of the methodologies evaluating the reliability performance of different technologies to provide system services (network security, balancing, and supply security) under a range of different assumptions.
- Chapter 4 proposes a set of test conditions for future trials considering a range of parameters that may affect the reliability of the EU-SysFlex solutions.
- Chapter 5 summarises the key findings and uptakes from the studies and provides practical recommendations on the next steps.

# 2. RELIABILITY ANALYSIS APPROACHES

## 2.1 GENERAL APPROACH: EQUIVALENT SERVICE DELIVERING CAPACITY OF EU-SYSFLEX SOLUTIONS

In this report, the concept of Equivalent Service Delivering Capacity (ESDC) is introduced. ESDC is defined as the capacity of traditional service providers that can be replaced by the capacity of the new service providers without compromising reliability quality considering the reliability performance difference and the interface between these two technologies. Figure 2.1 illustrates the ESDC concept.

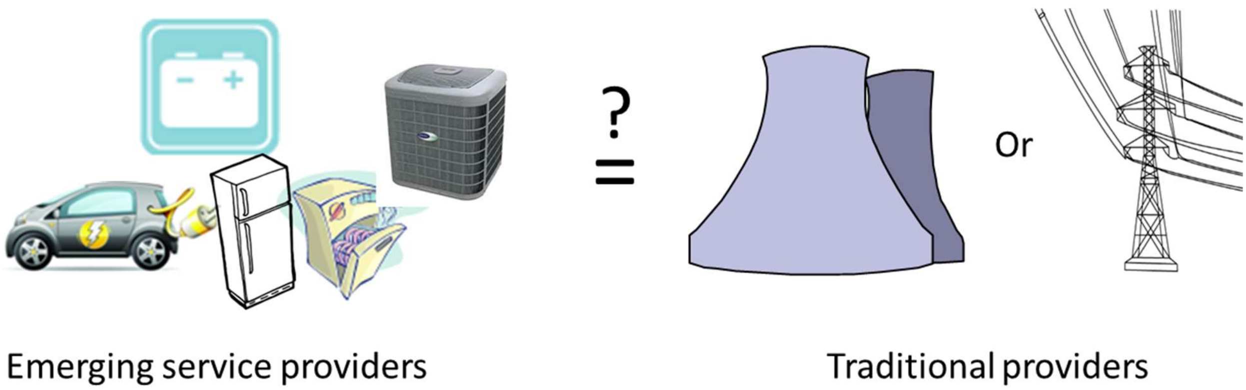


FIGURE 2.1 FINDING THE EQUIVALENT CAPACITY OF EMERGING EU-SYSFLEX SOLUTIONS COMPARED WITH THE CAPACITY OF TRADITIONAL SOLUTIONS

The left diagram constitutes a range of new grid service providers from various technologies, like those trialled in the EU-SysFlex project, such as EV and battery storage. The critical question from the system operator is how much they can rely on those services considering the reliability of individual small-scale resources is not as high as the reliability of conventional power generation or network assets. For example, the studies carried out in the Low Carbon London project[1] (based on real trials) showed a range of successful demand response rates between 84% and 98%. The response rates also vary seasonally, e.g. the rates are lower In winter.

Therefore, calculating the equivalent capacity from those resources as if they are from traditional resources will help the system operator using those resources to minimise the system operation costs.

## 2.2 GENERAL METHODOLOGY

The general principle of calculating ESDC is as follows:

- Identify the reliability metric that will be used for comparing the reliability performance of different cases; for example, Loss of Load Probability (LOLP), Loss of Load Expectation (LOLE), Expected Energy Not Supply (EENS), and others;

[1] G. Strbac, et.al. Distributed generation and demand side response services for smart distribution networks. Report A7 Low Carbon London project. Available at: https://innovation.ukpowernetworks.co.uk/wp-content/uploads/2019/05/LCL-Learning-Report-A7-Distributed-Generation-and-Demand-Side-Response-services-for-smart-Distribution-Networks.pdf

- Calculate the reliability metric of the counterfactual system with traditional solutions – it is worth noting that the reliability of the counterfactual system depends on the reliability of the traditional service providers;
- Calculate the reliability metric of the system with EU-SysFlex solutions;
- Find the point where the system's reliability with the EU-SysFlex solutions is equal to the reliability of the counterfactual system and determine the equivalent capacity.

An example to illustrate the concept is as follows: let assume a case where 1 million units of 1kW demand-side response can provide peak demand reduction service and assume that the ESDC metric of the aggregated 1 million units is 40%. It means that, on average, 40% of the units will be available or respond when the service is needed. The total expected capacity to be delivered is 40% x 1 M x 1 kW= 0.4 GW. Therefore, in this example, 1 GW of demand-side response provides the same reliability level of service as the 0.421 GW of a traditional service provider (e.g. a large-scale thermal plant), which has 95% reliability[2]. Of course, many parameters such as the number of service provider units and availability factor, to name a few, can affect ESDC, as discussed later in this report.

## 2.3 EVALUATION OF CAPACITY OUTAGE PROBABILITY TABLE

The basic model for assessing reliability is generally using capacity outage probability tables (COPTs). The theory relating to these is given in various reliability texts [1, 2]. Individual system component's capacity and associated availability are needed to calculate the capacity outage probability table. A two-state COPT is created for each system component, as shown in Table 2-1, where C and A are the capacity and availability of a system component.

**TABLE 2-1. TWO-STATE COPT**

| State | Capacity | State probability |
|---|---|---|
| 1 | C | A |
| 2 | 0 | 1-A |

If there is more than one system component, a summary COPT can be obtained by combining each state of one COPT with each state of the other COPT. The probability of a new combined state is a product of probabilities of combining states as $p_k = p_i \cdot p_j$ where: $p$ is the probability, $i$ and $j$ are the states of the combining tables, and $k$ is the state in the new COPT. Capacity depends on if the combination is assumed in parallel or series. For parallel, the capacity of a new state ($C_k$) is the sum of capacities of combining states ($C_i$ and $C_j$) as $C_k = C_i + C_j$. For series, the capacity of the new state is the minimum of capacities of combining states as $C_k = \min(C_i, C_j)$. COPT states are ordered in descending order by capacity. In multiple states with the same capacity, the combined state has the same capacity, and the new state probability is the sum of all state probabilities where the capacity is the same.

A cumulative probability is calculated once all possible combined states from all system components are determined in a single COPT. Cumulative probability ($CP$) for a particular state is the sum of probabilities where

[2] As the traditional sources are designed to provide services; their service reliability is close to 100%.

capacity is less than or equal to the state capacity, $CP_i = \sum_{j \in C_j \leq C_i} P_j$. Assuming a descending order of capacity, the cumulative probability is calculated from the lowest capacity state for which cumulative probability equals the state probability. The cumulative probability of a state is equal to the sum of the state probability and cumulative probability of the immediate state with lower capacity. Thus, the cumulative probability of the first state, the state with the largest capacity, is equal to 1.

The probability of delivery ($PD$) is calculated similarly to cumulative probability but starting from the first system state. The probability of delivery of the last state is equal to 1. The PD of a particular system state is measured by the likelihood of having a capacity greater than or equal to the system state capacity. The relationship between cumulative probability and probability of delivery for a particular system state could be written as $CP_i + PD_i - P_i = 1$.

The basic approach above is used and tailored to carry out some illustrative studies explained in the next chapter.

# 3. RELIABILITY EVALUATION

## 3.1 NETWORK SECURITY CONTRIBUTION

### 3.1.1 METHODOLOGY

Based on the theoretical studies using the concept described in the previous chapter, this section analyses DER's contribution to transmission network security. In this context, the presence of DER may enable network upgrade to be deferred. An illustrative example is given as follows. Assuming a single circuit could safely carry a load of 240 MVA, under N-1 condition, the maximum peak demand that could be supplied is 240 MVA, as illustrated in Figure 3.1. However, if DER can support an additional 60 MVA of demand, the maximum demand increases to 300 MVA. Using DER network services, the network upgrade could be deferred until demand reaches 300 MVA, as shown in Figure 3.2.

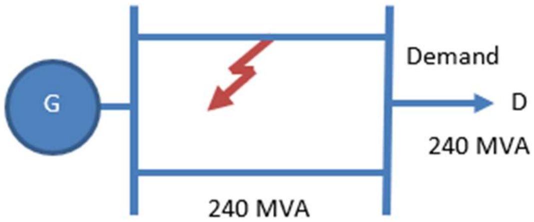


FIGURE 3.1. N-1 DISTRIBUTION DESIGN SUPPLYING 240 MVA DEMAND

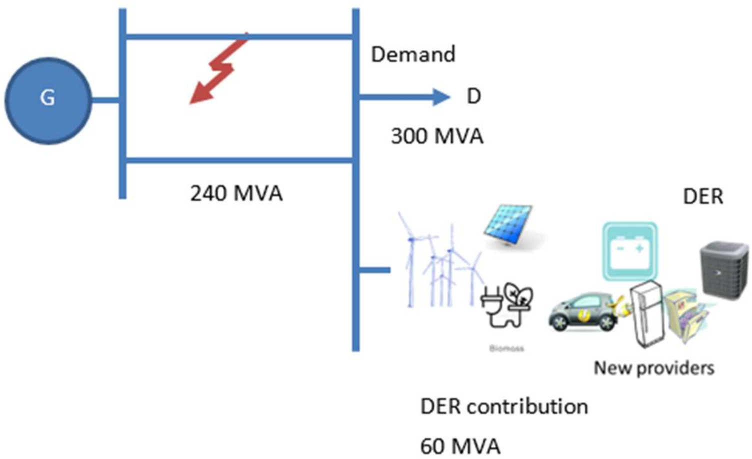


FIGURE 3.2. ILLUSTRATION OF NETWORK UPGRADE PARADIGM IN PRESENCE OF DER

Among many approaches for calculating DER contribution, the Effective Load Carrying Capability (ELCC) metric is widely accepted in the industry [3]. ELCC corresponds to the additional peak demand that can be accommodated in the system with DER while maintaining the same level of system security. Figure 3.3 illustrates the concept of ELCC. The risk metric is EENS.

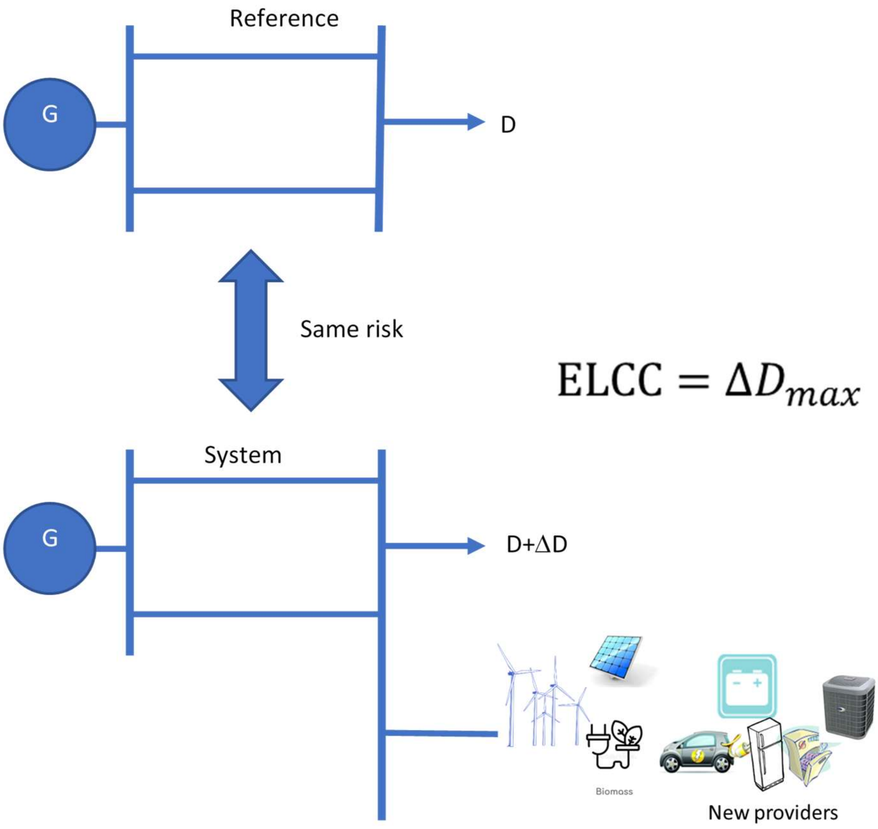


FIGURE 3.3. ILLUSTRATION OF ELCC

Figure 3.4 shows the change of Expected Energy Not Supplied for different assumed contribution levels of DER. The EENS of the network without DER is used as a reference. In this illustrative example, the reference EENS is 18 MWh per annum, represented by the red line. Without additional demand, DER flexibility will reduce system EENS to about 6.5 MWh per annum. Therefore, the demand in the system with DER can be increased until system EENS (represented by the blue line) is equal to the reference EENS of 18 MWh. As demand increases, denoted by contribution, system EENS starts to increase and will be the same as the reference EENS (for the original demand) when the demand increases. The increase in peak demand represents ELCC. Then the ESDC is equal to the ELCC divided by the total capacity of flexible demand, as shown in the x-axis. At this point, it can be determined that the ESDC of the aggregated DER is 42%. Increasing the demand further will increase the EENS, and the system will be less reliable than the reference system.

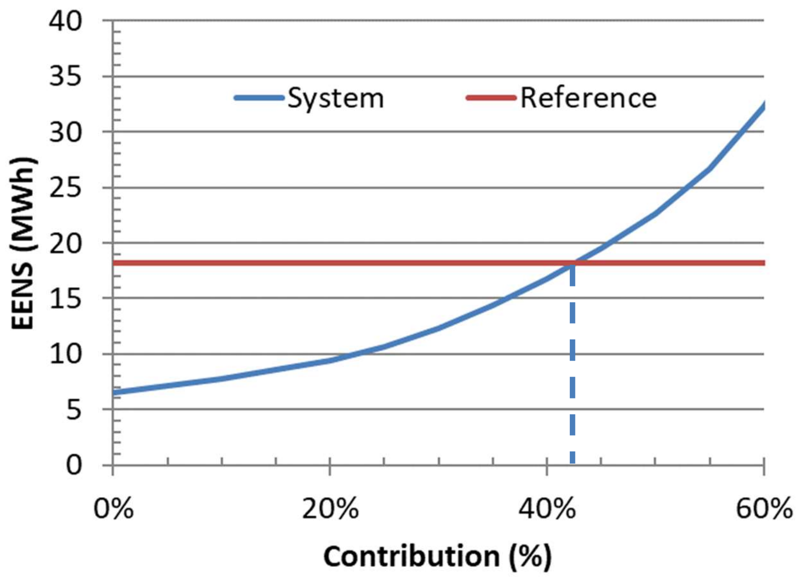


FIGURE 3.4. FINDING THE ELCC USING THE EENS AS A METRIC FOR RELIABILITY

Figure 3.5 shows the illustration of the system for transmission network reinforcement deferral. In this case, the contribution is calculated for the grid supply point, denoted by demand D. DER and distribution network are combined into equivalent DER, after which application of the ELCC approach, as described above, is straightforward. COPTs are created for DER and distribution networks as described in Section 2.3. Combining those two COPTs in series, an equivalent COPT, representing equivalent DER, is obtained.

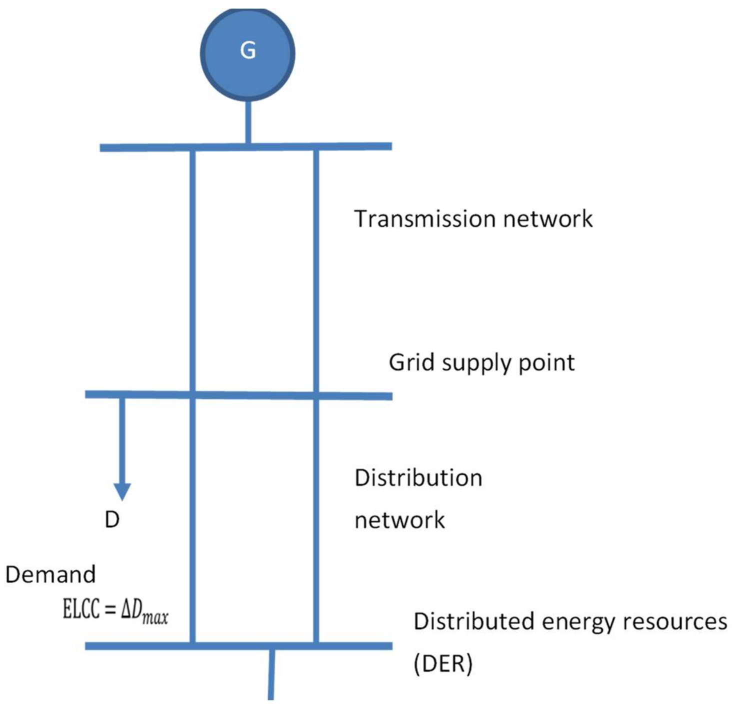


FIGURE 3.5. ILLUSTRATION OF NETWORK MODEL FOR CALCULATION OF DER CONTRIBUTION TO NETWORK CONGESTION MANAGEMENT

Drivers for DER contributions are DER number, rating and availability, transmission and distribution network circuits number, rating and availability, i.e., different circuit length and different construction (overhead or underground), and common-mode (dependency) between providers. The approach discussed in section 2.3 is used. Common-mode dependency is simulated by interpolation between cases where all DERs are independent and where all DERs are entirely dependent, i.e. equivalent to a single DER.

### 3.1.2 IMPACT OF NUMBER OF DER UNITS

Figure 3.6 shows the impact of the number of DER units on their contribution to network security based on the illustrative system shown in Figure 3.5. In this example, DER (bottom part of Figure 3.5) will be utilised to facilitate increased demand at the grid supply point while avoiding transmission network reinforcement. In all cases, the total DER capacity is the same and equal to 120 MW. Availability of each DER is assumed 90%. The reliability performance of transmission and distribution networks is also considered. However, the impact is found negligible when enough network capacity is available.

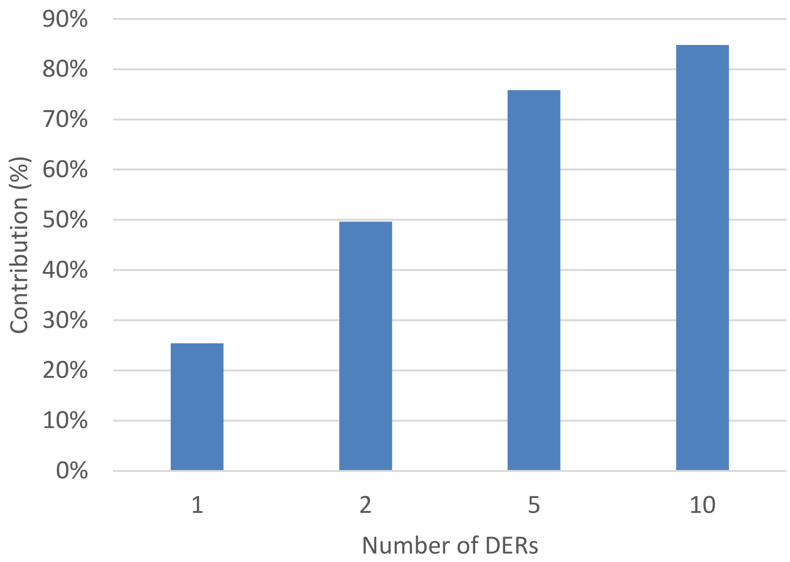


**FIGURE 3.6. IMPACT OF DER PARAMETERS**

The lowest contribution[3] is for one unit, given a higher probability that all capacity will be in an outage. Having more DER units will increase the overall contribution, considering that the likelihood of delivering grid services is typically higher than that of fewer units. For example, with two units, the contribution increases to 50%. Five and ten units result in 75% and 85% contribution, respectively. The results indicate that the DER services will be more reliable if the services are provided by many units instead of only one.

Figure 3.7 shows the probability of delivering the contribution specified in Figure 3.6. For a single DER facility, the probability of delivery is equal to the availability. For example, to deliver a 25% contribution, a unit needs to be available, and since a unit's availability is 90%, the probability of delivery contribution is 90%. The highest probability of delivering of 99% is observed for two DER units. The contribution of two DER units is slightly lower than 50%, meaning that only one DER facility needs to respond to deliver the contribution. The probability is high (99%) since

[3] The contribution factor determines the ratio between the increased demand at the grid supply point and the DSR capacity while maintaining the same reliability criterion.

DER cannot deliver the service only when both units fail. For ten DER units, the contribution of about 85% (102 MW) could be delivered by at least nine units available; the likelihood is 74%.

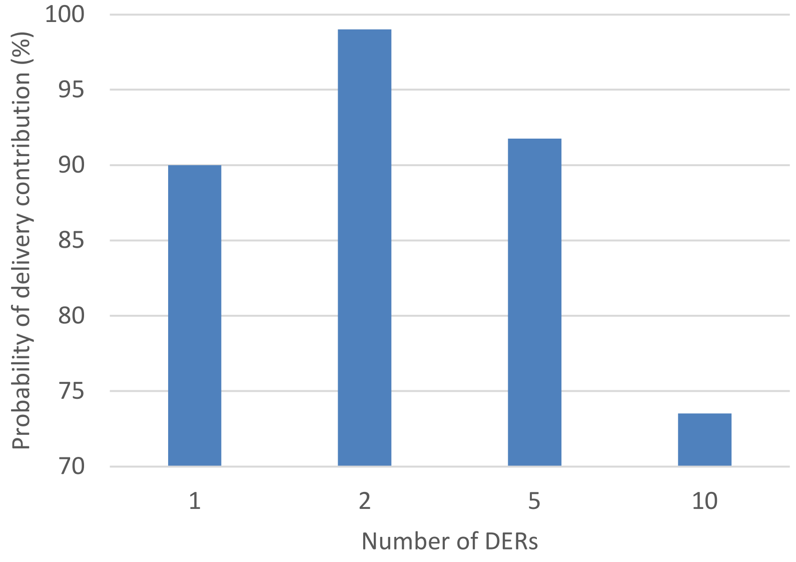


FIGURE 3.7. PROBABILITY OF DELIVERING CONTRIBUTION

It is worth noting that for the same level of contribution, the higher the number of units, the better.

### 3.1.3 IMPACT OF CONFIDENCE LEVEL

More DSR should be contracted than needed by the value of contribution alone to increase the probability of delivery. In Figure 3.8, the contribution is calculated based on the services delivered with a confidence level of 95%. Observed contribution for five and ten DSR units is broadly 15% lower than shown in Figure 3.6. For two DSR units, it is just slightly higher at 50%, and for one DSR, the facility contribution is zero given the availability of 90% is lower than desired confidence level.

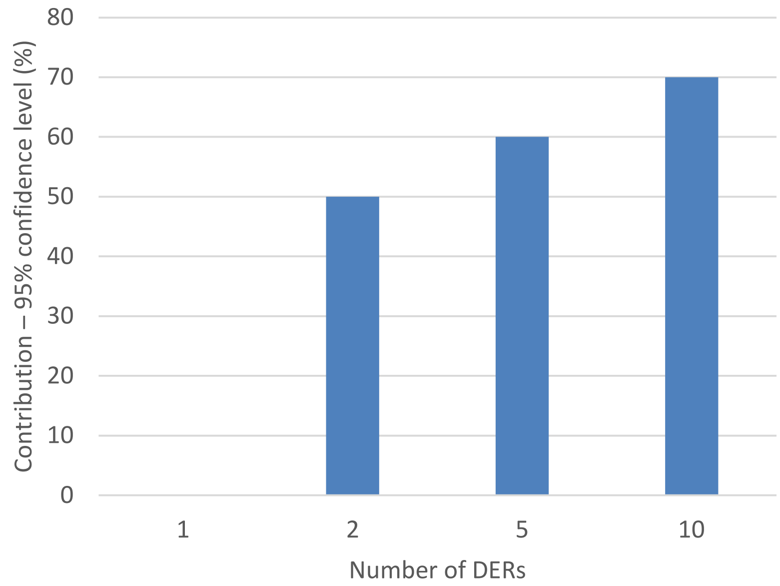


FIGURE 3.8. ESDC CONTRIBUTION WITH CONFIDENCE LEVEL OF 95% OF CONTRIBUTION BEING DELIVERED

The ESDC contribution is affected by the confidence level requirement. This aspect could be part of the contractual negotiations between providers and users of flexibility.

### 3.1.4 IMPACT OF LOCAL NETWORK CONSTRAINT

Figure 3.9 shows the illustrative example where limited local distribution network capacity could impact the ESDC of DSR. Assumed transmission capacity is 2 x 240 MW with a failure rate of 2% per annum per circuit (1 in 50 years chance of an outage of each of the circuits), assuming an average repair time of 1440 hours. Due to the relatively high transmission capacity and the corresponding availability, the impact of transmission is found to be modest. In this case, one transmission circuit is enough to allow generation led DER to provide service. At distribution, two distribution circuits capacity of 30-90 MW per circuit are used in this study. The failure rate ($FR$) is also assumed 2% per annum and circuit, but the average repair time ($RT$) is shorter at 240 hours. Two DSR units are assumed, each of 60 MW and availability of 90%. A circuit availability is calculated as $A = \frac{1}{1+FR \cdot RT}$.

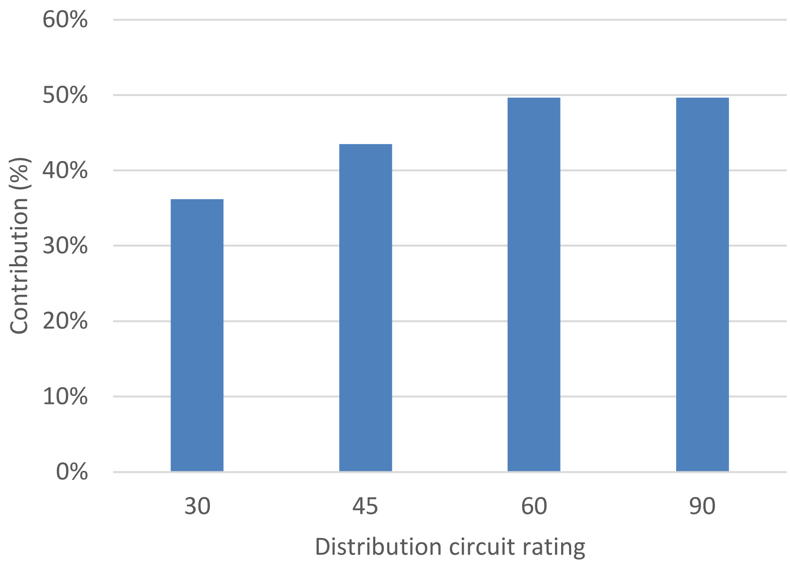


FIGURE 3.9. IMPACT OF LIMITED DISTRIBUTION NETWORK CAPACITY

Circuit capacity impacts only when its capacity is lower than DSR rating, i.e., lower than 60 MW per distribution circuit. For example, if the capacity of each circuit is 30 MW, the contribution is about 36%. Thus, the contribution is about 30% lower than in 60 MW per distribution circuit capacity case. It is anticipated that the circuit capacity would be typically greater than the DSR rating, and hence the impact of the distribution network on ESDC would be negligible.

### 3.1.5 IMPACT OF COMMON-MODE FAILURES

Figure 3.10 shows the impact of DER common-mode failures. The example is shown for ten DER units each of 12 MW and availability of 90%. If there is no common-mode dependency, the overall contribution of these ten DER units is 85% (as previously shown in Figure 3.6. In this case, all units are independently considered. If the common-mode dependency is 25%, the overall contribution is reduced to 79%. If all units are considered in unison, i.e. common-mode dependency is 100%, the contribution is reduced to 25%. This contribution is equivalent, in this example, to the case of one large DER facility of 120 MW (Figure 3.6). With greater dependency between DER units, the contribution is lower. In this example, transmission and distribution network reliability performance is considered but found no discernible difference in overall results.

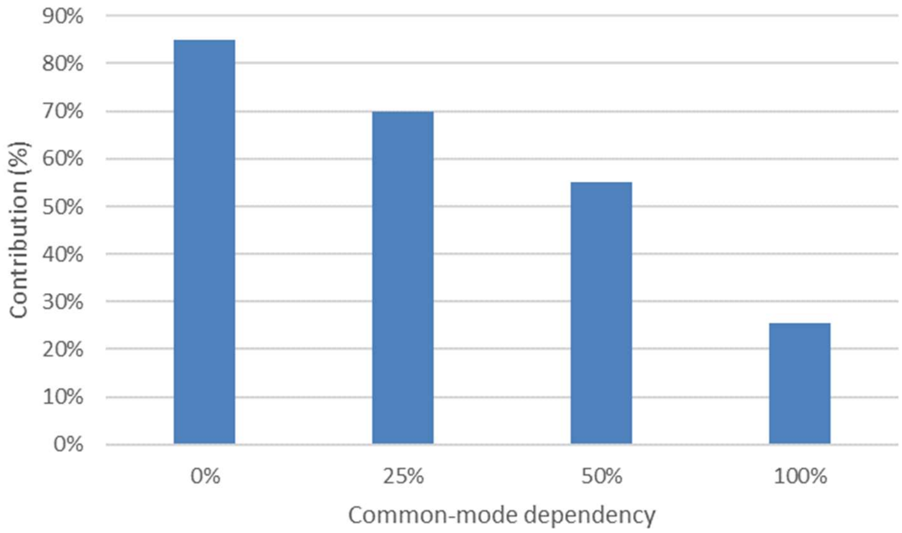


FIGURE 3.10. IMPACT OF DER COMMON-MODE FAILURES

### 3.1.6 SUMMARY OF IMPACT OF DER ON NETWORK SECURITY CONTRIBUTION

The ESDC of DER units is affected by the number of DER units providing the service. The lower the number, the contribution tends to be lower although the total DER capacity is the same. This is driven by the likelihood of delivering part or full of the services; the lower the number, the likelihood of not delivering the service may increase. As demonstrated previously (e.g. in Figure 3.6), the contribution for five DER units is about three times greater than the observed contribution for one DER facility with the same total DER capacity. Desired minimum probability of delivery could be specified in the contract of service if needed. The approach to calculating the number of DER facilities needed to achieve the desired delivery probability is described in the report. Distribution circuit capacity reduces generation-led DER contribution only when it is lower than the DER rating. This aspect should be tested in distribution networks with lower reverse power flow capability. Greater dependency between DER units results in a lower ESDC metric.

## 3.2 SYSTEM BALANCING CONTRIBUTION

DER could potentially provide balancing services to reduce the need for spinning and standing reserve from conventional generators or reduce the curtailment of renewable sources. Flexible loads from DER can follow the output of variable RES and be interrupted in an emergency if the system frequency suddenly drops substantially following significant infeed loss from generators or interconnectors. Given the relatively short nature of service duration need, the analysis assumes constant system balancing requirements across the service providing period.

Figure 3.11 illustrates an example where DERs can work together with conventional resources to provide balancing services. The system consists of a network where transmission connected conventional generators and DER at distribution provide balancing services to support transmission system operation. DERs may provide balancing services more efficiently and cost-effectively, reducing the need for conventional generations to run part-loaded and improving overall system operation efficiency. Since the balancing services are needed at transmission and DERs are connected at distribution networks, the constraints at distribution and transmission networks could impact the level of balancing services DER could provide. In case of a shortfall in the generation, DER could, for example, reduce demand or discharge storage. In case of excess generation, DER could, for example, increase demand or charge storage.

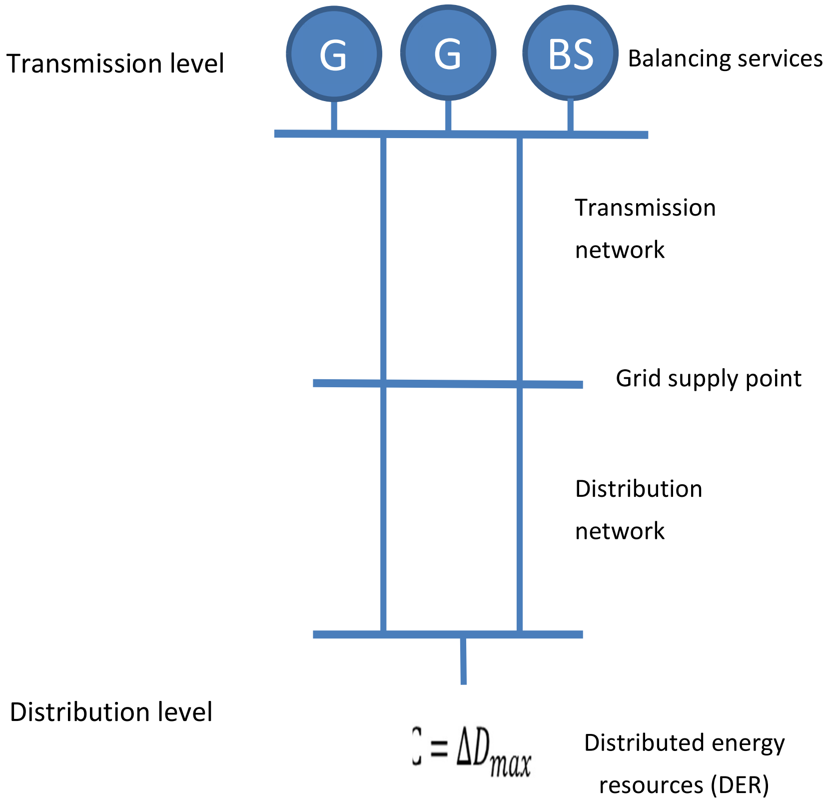


FIGURE 3.11. ILLUSTRATION OF BALANCING SERVICES

The designated approach for calculating the contribution of DERs is based on the equivalent DER considering the reliability of the distribution and transmission network. DERs, distribution and transmission networks are represented each by a COPT. The COPT representing equivalent DER is obtained by combining COPTs of DERs, distribution and transmission networks in series. For a specified confidence level, a maximum capacity for which the probability of delivery is greater than or equal to a specified confidence level is the contribution of DER to system balancing. Dividing such capacity with the total DER capacity, the ESDC credit is obtained.

An example is given as follows to illustrate the approach. Let us assume 100 independent DER units connected to the system where balancing services are provided by generation running at minimum stable generation. Each DER facility is 100 kW (10 MW in total) that can provide balancing services with an availability of 60%. From the system operator perspective, the main question is how much of conventional balancing services capacity could be displaced by providing service from DER assuming a required confidence level of 95%?

A curve showing the probability of delivery of available DER capacity is shown in Figure 3.12. For example, with a 20% probability of delivery, the maximum DER capacity that can be delivered is greater than or equal to about 6.5 MW.

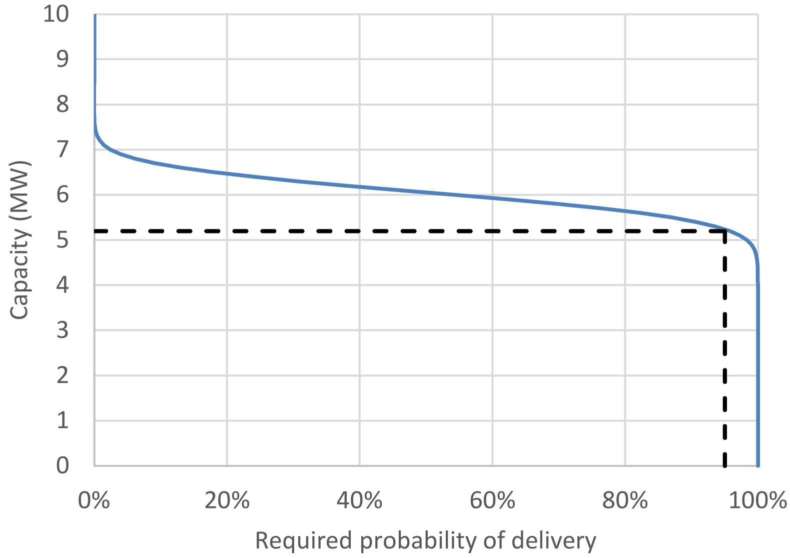


FIGURE 3.12. CAPACITY VS REQUIRED PROBABILITY OF DELIVERY

Dividing the Y-axis capacity with the total DER capacity, in this example, 10 MW, the EDSC is obtained as shown in Figure 3.13.

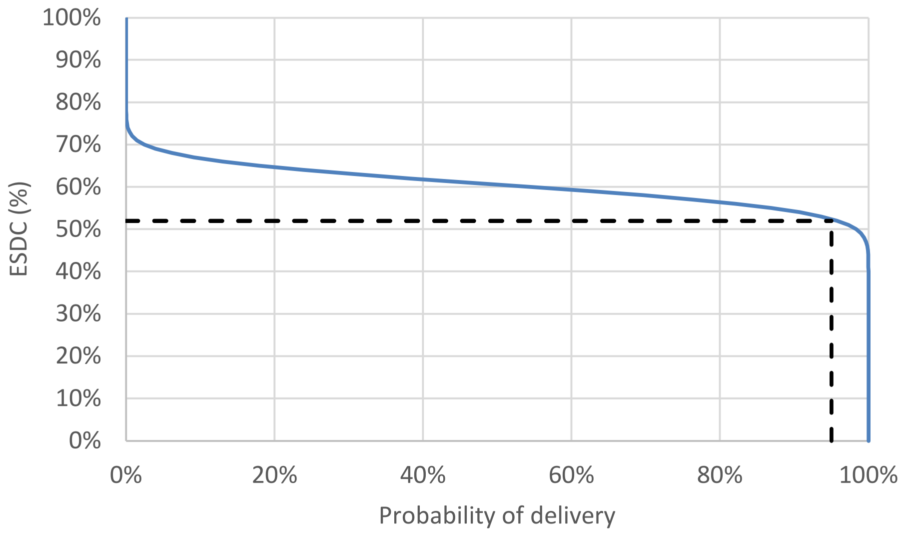


FIGURE 3.13. EQUIVALENT SERVICE DELIVERING CAPACITY VS REQUIRED PROBABILITY OF DELIVERY

Considering the required confidence level of 95%, the graph above shows that about 5.2 MW (out of 10 MW) could be offered to the system operator. This corresponds to an ESDC of 52%. For a lower confidence level, DERs can offer a higher service capacity and vice versa.

Figure 3.14 shows the example of the contribution of DER to balancing services for a different number of DER units and DER availability, assuming a confidence level of 95% of contribution being delivered. For a single unit, when the DER availability is lower than the desired confidence level, the DER contribution is zero. The contribution is higher when more DER is deployed, although the total DER capacity remains the same. For example, in cases with 10 and 100 DER facilities with 80% availability of each DER, the contribution is about 60% and 73%, respectively. The total DER capacity in both cases is the same, i.e. 10 MW. Having a higher number of DER units improves the reliability of the services at a specified confidence level.

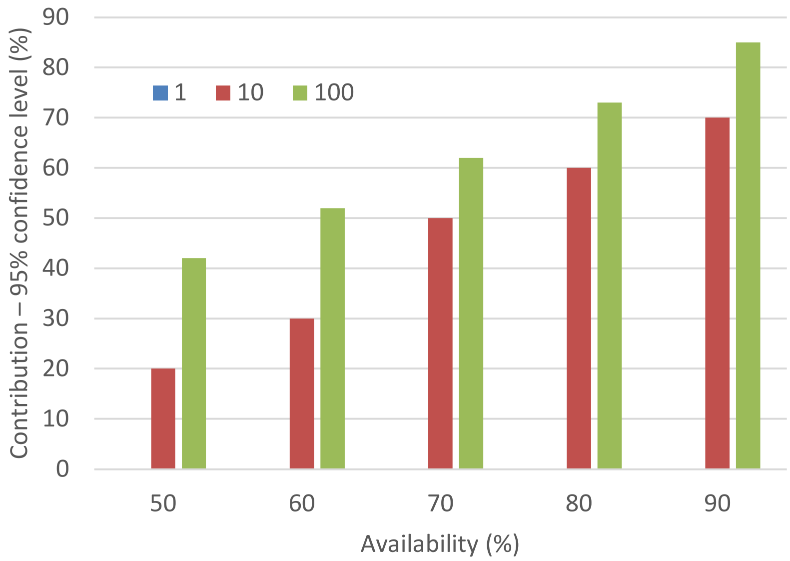


**FIGURE 3.14. ILLUSTRATION OF CONTRIBUTION OF DER TO BALANCING SERVICES FOR DIFFERENT AVAILABILITY AND NUMBER OF DER UNITS FOR CONFIDENCE LEVEL OF 95%**

There is no significant impact of distribution and transmission network reliability on contribution due to the lumpiness of system states likelihood. For example, for 10 DER facilities and the availability of each DER of 80%, the contribution is 60%. The probability of delivering a contribution of 60% is 96.721% if network reliability is not considered. If network reliability is considered, the contribution is still 60% but with a slightly lower probability of delivering contribution at 96.620% if each distribution and transmission network circuit fails once in 5 years. The confidence level of 95% is satisfied in both cases.

More DER units with the same total capacity and availability typically provide a higher contribution. For example, battery storage could be considered a single high reliable DER facility while a group of vehicle-to-grid fleets may have high uncertainty on their temporal availability but represents a high number of devices, distributed DER.

Figure 3.15 shows the contribution if the desired confidence level is increased to 99%. As expected, the contribution is decreased. For the same example above, the contribution of 10 DER units with 80% availability is 50% if the confidence level is set to 99%. This is a decrease of 10% compared to the previous results with a confidence level of 95%, shown in Figure 3.14.

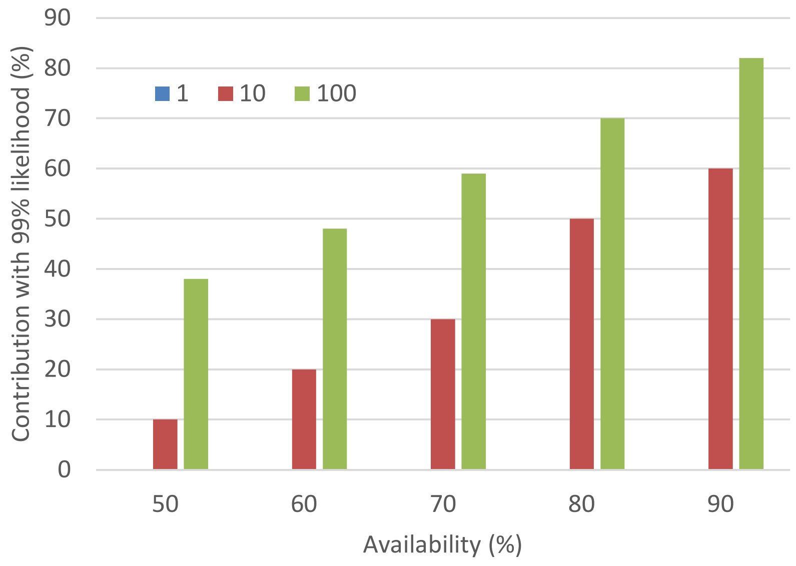


FIGURE 3.15. ILLUSTRATION OF CONTRIBUTION OF DER TO BALANCING SERVICES FOR DIFFERENT AVAILABILITY AND NUMBER OF DER UNITS FOR CONFIDENCE LEVEL OF 99%

### 3.2.1 IMPACT OF LOCAL DISTRIBUTION CONSTRAINTS

Figure 3.16 shows the result when available distribution network capacity limits the contribution DER using the same parameters and confidence level as shown in Figure 3.14. High-capacity DER connected to a local distribution network could be limited by the network's rating. Again for 10 DER facilities with 80% availability, the contribution is reduced to 50%, i.e. reduction of 10%.

If all DER are located in the same local network, the network might be overloaded. Distributing DER contracts to a wider area could mitigate such issues.

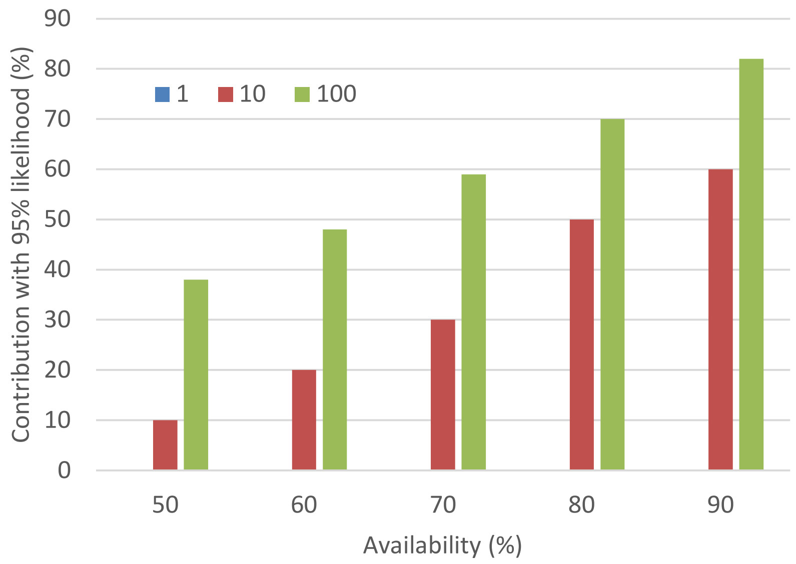


FIGURE 3.16. ILLUSTRATION OF CONTRIBUTION OF DER TO BALANCING SERVICES FOR DIFFERENT AVAILABILITY AND NUMBER OF DER UNITS FOR CONFIDENCE LEVEL OF 95% WHEN TOTAL DER RATING IS LIMITED BY DISTRIBUTION NETWORK RATING

### 3.2.2 SUMMARY OF SYSTEM BALANCING CONTRIBUTION

In summary, having more DER facilities increases diversity and ESDC. The contribution of a single DER facility is zero if DER availability is lower than the specified confidence level; otherwise, it is 100%. Typically, having more DER units leads to a higher aggregated contribution except for the case with a single DER facility with availability greater than the specified confidence level. There is no observed visual impact of distribution and transmission network reliability on contribution due to relatively higher network capacity than the total DER capacity, resulting in a high probability of network capacity higher than the total DER capacity. If the system operator accepts a lower confidence level, DERs can have a higher contribution.

There is a wide range of availabilities depending on DER technology. For example, dedicated battery storage could be a single facility but highly reliable. On the other hand, the temporal availability of a group of vehicle-to-grid may be uncertain, which tends to reduce its contribution, but as they consist of many distributed devices, this reduces the risk and improves the contribution. Therefore, the system operator will require a tool to help them understand the impact of all those factors on the reliability performance of the DER services.

Another factor is that the network's rating could limit high-capacity DER(s) connected to a local distribution network. Furthermore, reverse power flow rating could be significantly lower than normal rating and, in some conditions, DER could be limited. If all DER connected to a local network responds, the local network might be overloaded. DER contracts should be distributed to a broader area to mitigate such issues.

## 3.3 SUPPLY SECURITY CONTRIBUTION

The flexibility from distributed resources can reduce the electricity peak demand resulting in less generation capacity needed to maintain security. However, other factors such as storage capacity and the electricity load profiles may also affect how much peak demand reduction can be achieved, in addition to other factors that have been discussed previously.

In this context, the security contribution of distributed resources, particularly electricity storage, can be calculated using an ESDC factor. The ESDC reflects an energy storage unit's contribution to the security of supply.  For example, an ESDC equal to 50% means that the storage unit connected to a load bus can reduce the peak load by 50% of its power capability.

The ESDC is a dimensionless metric that is defined as a ratio between the numerator (P), i.e. the optimal (i.e., maximum) reduction in peak demand, and the denominator ($P^{cap}$) is the power capability of the energy storage plant. Equation (1) below shows this relationship.

$$ESDC = \frac{P}{P^{cap}} \quad (1)$$

In addition, to calculate the ESDC metric, it is essential first to conduct an optimisation study to obtain the numerator, i.e., the maximum peak demand reduction, which is discussed in the next section.

A system shown in Figure 3.17 is used to illustrate the concept. For example, if the peak demand is equal to 7,035 kW, and after optimal storage operation, the peak reduces to the level of 6,821 kW, the peak demand reduction is equal to 214 kW. Assume that the storage power capability is equal to 703.5 kW (i.e., at the level of 10% of the peak) and the storage duration is equal to 1 h; this means that it takes 1h for the unit to charge or discharge fully.

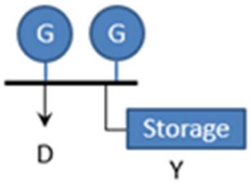


FIGURE 3.17. TOPOLOGY FOR THE SYSTEM UNDER STUDY. THERE IS AN ENERGY STORAGE PLANT CONNECTED TO A BUSBAR. THERE IS ELECTRICITY DEMAND (D) CONNECTED AS WELL AS GENERATION CAPACITY (G).

Then, the ESDC is 214/703.5 = 30.4%. This means that the storage unit can reduce the peak demand by around 30% of its power capability. This information is vital as it can help network planners select energy storage size optimally, thereby avoiding investments involving oversized energy storage units since storage units of larger sizes do not necessarily yield a higher peak reduction. Thus, system planners or investors can use the calculation of the ESDC metric to avoid suboptimal investment costs.

### 3.3.1 THE ESDC METHODOLOGY FOR SUPPLY SECURITY CONTRIBUTION

The previous section mentioned that ES technology could bring various benefits to the electricity system, including the provision of security of supply, which can be evaluated using the ESDC methodology.

ES units can operate in such a way that can lead to peak reduction. Specifically, by discharging their stored energy, they can supply electricity to nearby demand centres, thereby alleviating the congestion on network assets across the grid and reducing peak demand. When the system demand is low, the ES plant is charged; this charge is subsequently released during peak or near-peak demand, consequently reducing the peak. By shaving off the peak demand, the ES can trigger deferral of conventional network reinforcement that would otherwise be required to be deployed for the safe accommodation of power flows. Such ES operation can contribute to the security of supply because a sudden loss of a critical network asset during peak demand may lead to interruptions in electricity supply to consumers. Hence, peak reduction through energy storage operation contributes to the security of supply.

The current work presents the application, for the first time, of the ESDC metric for the evaluation of the energy storage security contribution. Specifically, the ESDC metric is defined as the ratio of P, which stands for the optimal reduction in peak demand (kW), over $P^{cap}$, which stands for the power capability (kW) of the ES plant, as in Equation (1). In this regard, this metric is dimensionless and is expressed in percentage terms.

From Equation (1), an optimisation study considering the technical characteristics of storage and the system demand is needed to obtain the maximum peak demand reduction to calculate the ESDC. Therefore, the mathematical formulation for the corresponding optimisation problem is provided below.

As the ESDC metric depends on the characteristics of the energy storage unit, it is essential to perform sensitivity analysis and examine how the ESDC measure is affected by the load characteristics, such as the shape of the demand profile and characteristics of the energy storage, such as the efficiency and the time required for a full charge/discharge of the ES plant. This is also performed further below in this report.

The modelling approach for calculating the ES security contribution is based on solving a deterministic linear and continuous optimisation problem, where the objective is to minimise the peak demand (kW) through optimal storage operation.

$$minimize\ P_{max} \tag{2}$$

$$P_{max} \geq D_t + P_t^{in} - P_t^{out}\ \forall\ t \in T \tag{3}$$

$$E_t = E_{t-1} + \delta \cdot \eta \cdot P_t^{in} - \delta \cdot P_t^{out}, \qquad \forall\ t \in T^* \tag{4}$$

$$E_t = I \cdot \tilde{E} + \delta \cdot \eta P_t^{in} - \delta \cdot P_t^{out}, t = 1 \tag{5}$$

$$E_1 - E_T = 0, \forall d \tag{6}$$

$$\widetilde{E_{min}} \leq E_t \leq \widetilde{E_{max}}, \forall\ t \in T \tag{7}$$

$$P_t^{in} \leq \tilde{P}\ , \forall\ t \in T \tag{8}$$

$$P_t^{out} \leq \tilde{P}\ \forall\ t \in T \tag{9}$$

The objective function (2) aims to minimise the maximum net demand, represented by the variable $P_{max}$, which by default is greater than the net demand across all periods (3). Net demand is defined as the summation of the initial demand represented by the input parameter $D_t$ (kW), with the power that charges the ES plant, $P_t^{in}$ , (kW), minus the power that is discharged from the ES, $P_t^{out}$ (kW); both are decision variables. As can be seen, there is no cost involved in the objective function. Instead, for calculating the ESDC, the objective is to minimise peak demand through optimal storage operation.

Constraint (4) models the operation of the ES device. Essentially, the state of charge (SOC) $E_t$ (kWh) at period t is equal to that at period t-1 plus the energy that charges the ES plant at period t minus the energy which gets discharged at the same period, where n is the efficiency of charging (p.u.). Furthermore, parameter $\delta$ (hours) represents the time-granularity of the load data; for example, $\delta$=0.5 for load-data, where each period corresponds to half an hour or $\delta$=1 for hourly granularity. The constraint models the operation of ES as a load during off-peak periods (i.e., charging with energy) and as a generator (i.e., discharging) during peak times.

Constraint (5) is the application of (4) to the first period. Notice that I (p.u.) is a decision variable that specifies the initial SOC of the ES, and $\tilde{E}$ is the storage capacity (kWh). Constraint (6) states that the SOC at the last horizon period equals the SOC in the first period. Constraint (7) specifies the upper and lower bounds for the SOC, which are typically expressed as a percentage of the energy capacity. Limitations also apply to the power capability; specifically, the power that charges ES (8) and that which is discharged (9), at period t, must be less than or equal to the power capability of ES as represented by the input parameter $\tilde{P}$.

In the following section, we proceed to present case studies that illustrate the concept further.

#### 3.3.1.1 DESCRIPTION OF THE CASE

This section presents the case study used to crystalise the concept of the ESDC. Figure 3.17 displays two charts illustrating the concept, where each chart shows two daily normalised load profiles. Note that by "normalised", the load is expressed between 0 (no load) and 1 (peak load).

The profile shown with a black line, i.e., profile 1, is the peaky one, while the profile with the blue line, i.e., profile 2, is less peaky (flat). In addition, it is worth noting that the figure on the left corresponds to the case where both profiles have a half-hourly peak duration, while that on the right corresponds to a 3-hour peak duration.

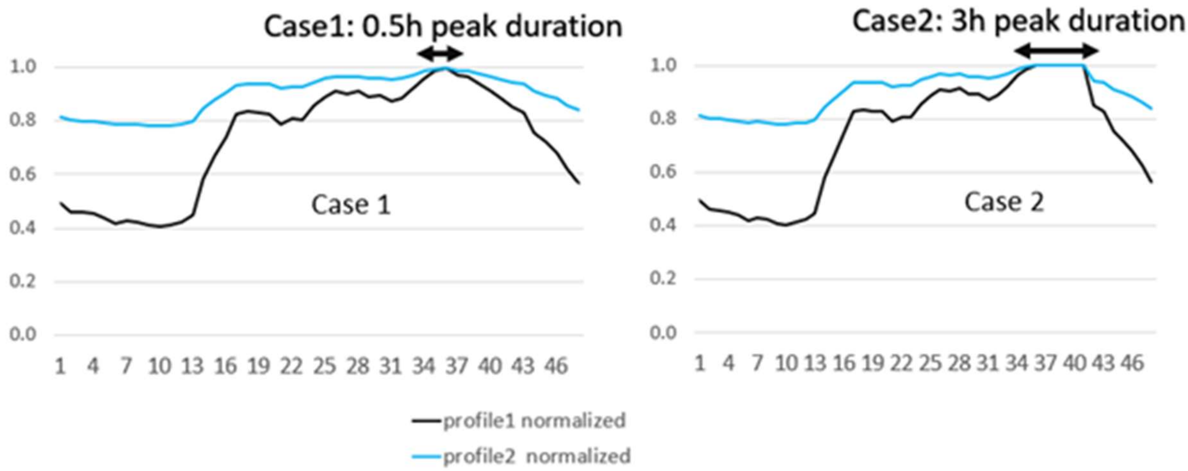


FIGURE 3.18 GRAPHS SHOWN THE TWO PROFILES, I.E., PEAKY PROFILE (IN BLACK) AND FLAT PROFILE (IN BLUE).

### 3.3.1.2 CASE STUDY1: ESDC AS A FUNCTION OF STORAGE POWER CAPABILITY

The ESDC metrics for the two cases described in the previous section are calculated using the method described in section 3.3.1. Figure 3.19 is a bar plot that corresponds to the case of half-hourly peak duration, while Figure 3.20 corresponds to the case of the three-hour peak duration.

Note that the horizontal axis shows different storage durations (i.e., 1h, 4h, 8h), as well as different storage efficiency levels (i.e., 60% and 100%) as well as different load profiles (peaky profile 1 and flat profile 2). In addition, the colour of the bars corresponds to the different storage power capability levels, with the black colour corresponding to 10%, and blue corresponding to 30%, while yellow corresponds to 50%.

The values of the bars represent the ESDCs for the storage unit. As such, we can observe that the ESDCs reduce as the energy storage power capability increases. In addition, we observe that the ESDCs for the peaky profile are higher than those for the flat profile. It can be observed that these conclusions apply regardless of storage efficiency, storage size or storage duration.

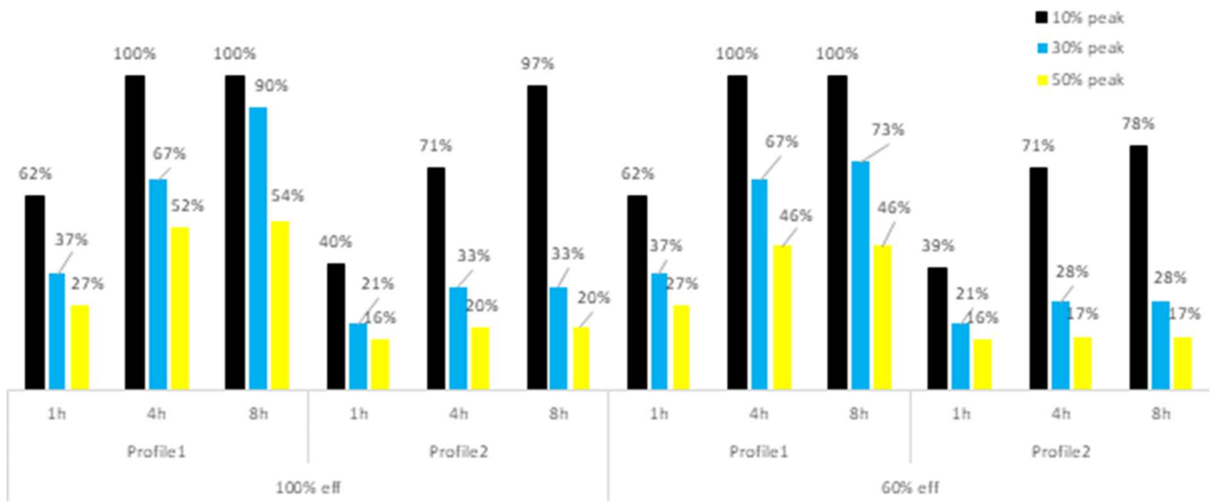


FIGURE 3.19 ESDC AS A FUNCTION OF STORAGE POWER CAPABILITY (HALF-HOUR PEAK DURATION)

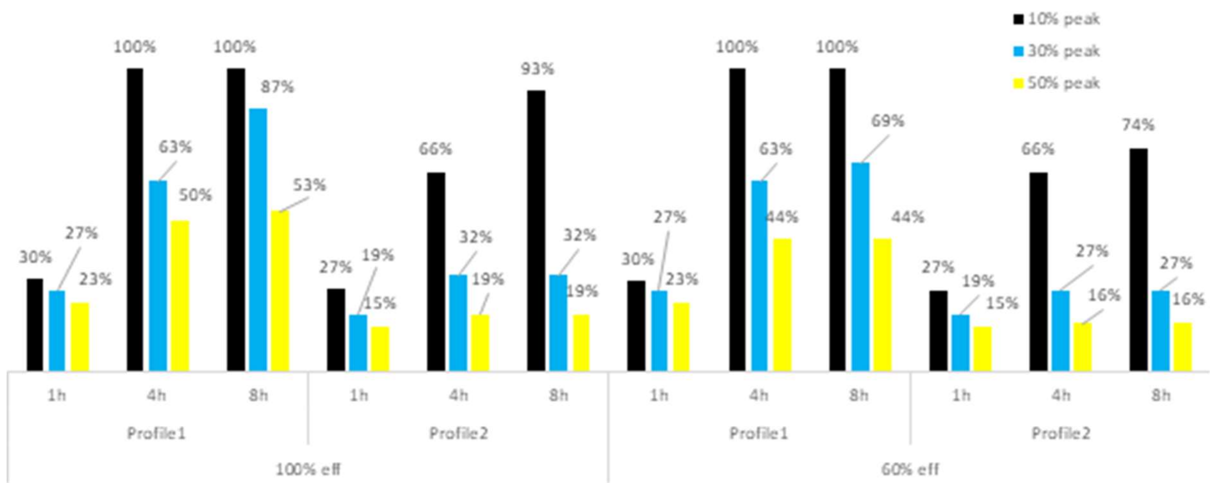


FIGURE 3.20 ESDCS AS A FUNCTION OF STORAGE POWER CAPABILITY (THREE-HOUR PEAK DURATION)

The following section describes the impact of different load profile characteristics on the ESDC metric.

#### 3.3.1.3 CASE STUDY 2: IMPACT OF THE FLATNESS OF DEMAND PROFILE

In this section, the impact of having different demand profiles is discussed. Figure 3.21 corresponds to the case of half-hourly peak duration, while Figure 3.22 corresponds to the case of three-hour peak duration.

The horizontal axis shows the different energy storage duration levels (1h, 4h, 8h), storage efficiency levels (100% and 60%) as well as storage power capabilities (10%, 30%, 50%). In addition, the colours of the bars correspond to different profiles. The black corresponds to the peaky profile1, and the blue corresponds to the flat profile2.

The values of the bars reflect the level of the ESDCs for the energy storage unit. The modelling results suggest that the ESDCs for the peaky profile are higher than those for the flat profile. It can also be observed that these conclusions apply regardless of storage efficiency, storage size or storage duration.

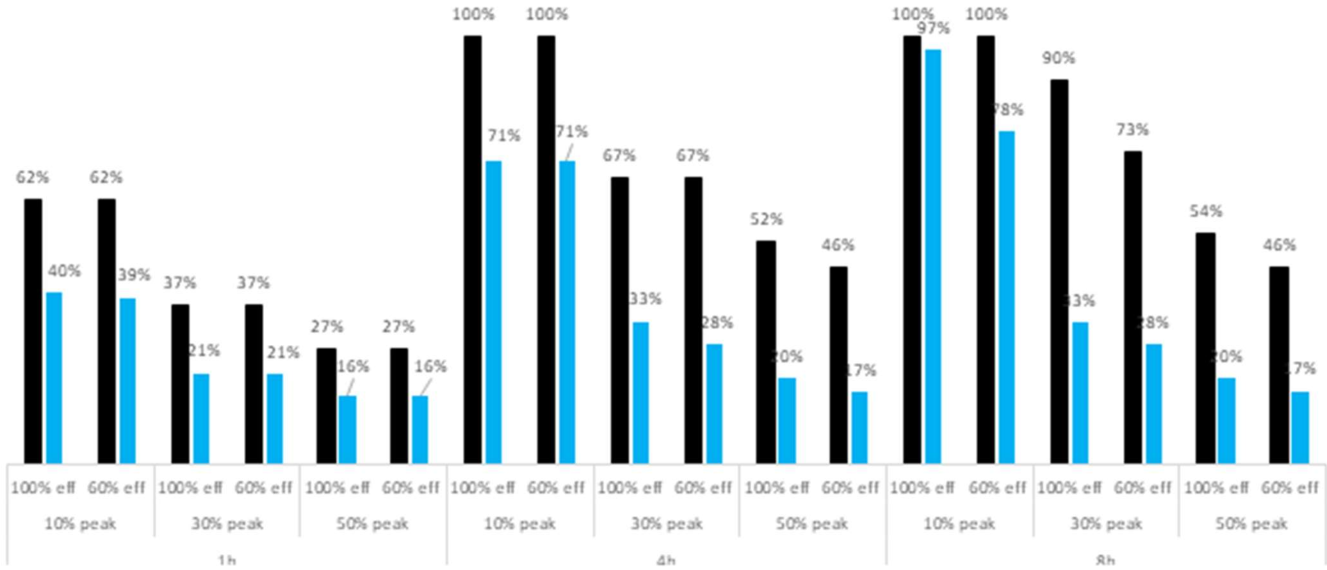


FIGURE 3.21 ESDC AS A FUNCTION OF STORAGE POWER CAPABILITY (HALF-HOUR PEAK DURATION)

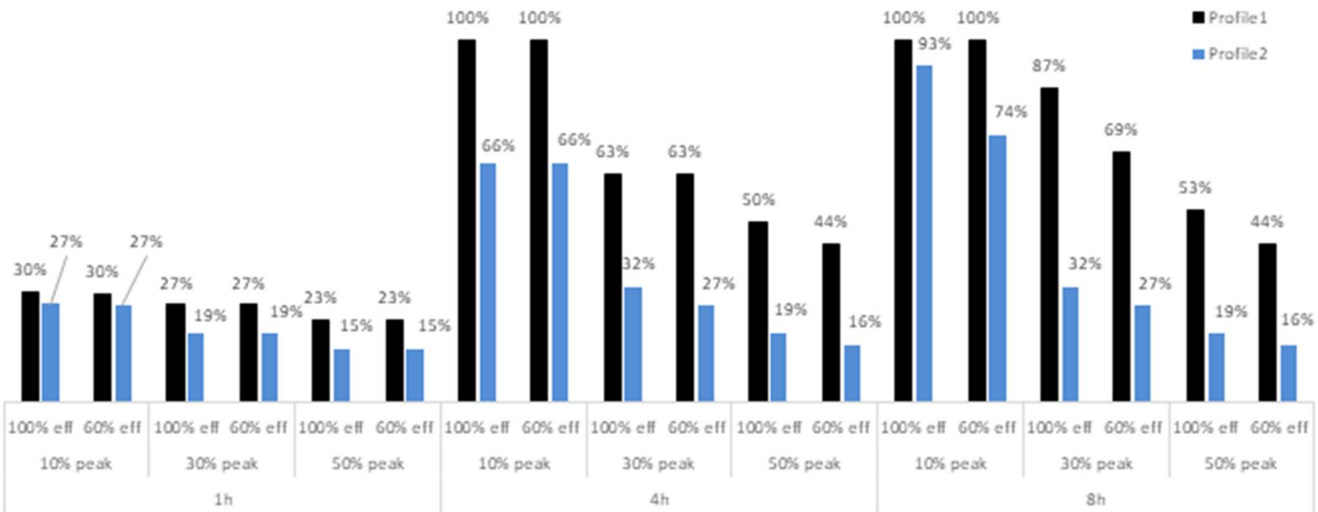


FIGURE 3.22 ESDC AS A FUNCTION OF STORAGE POWER CAPABILITY (THREE-HOUR PEAK DURATION)

### 3.3.1.4 CASE STUDY 3: IMPACT OF THE PEAK DURATION

Figure 3.23 presents the ESDCs as a function of the peak duration. The horizontal axis shows different storage duration levels (1h, 4h, 8h), different storage power capabilities (10%, 30% and 50%) and load profiles (peaky profile1 and flat profile2). In addition, the colours of the bars correspond to different peak durations, i.e., black is for the half-hourly peak, and blue is for the 3-hour peak.

It can be observed that the ESDCs for the half-hourly peak duration are higher than those for the 3-hour peak duration.

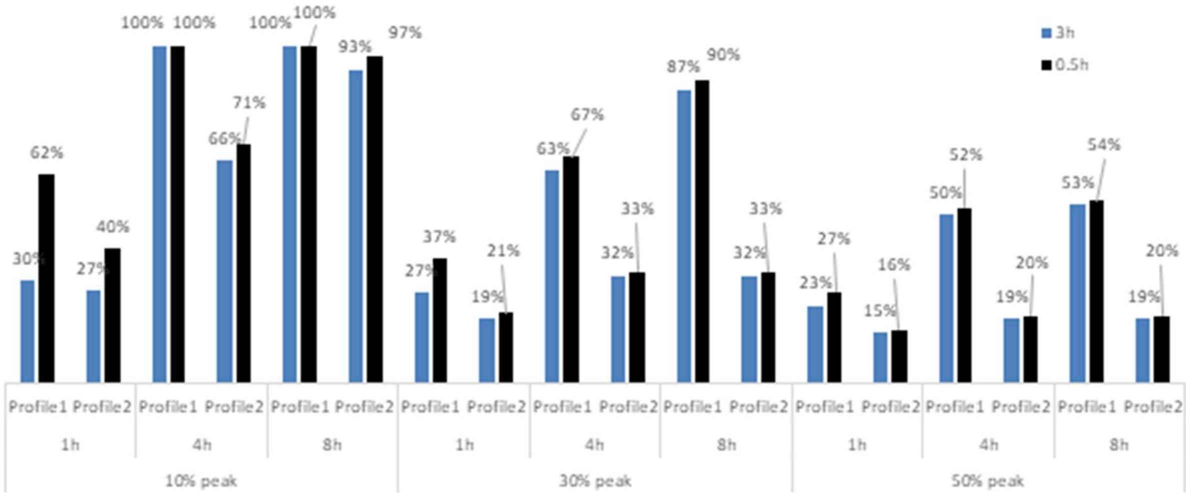


FIGURE 3.23 ESDCS AS A FUNCTION OF THE LOAD PROFILE PEAK DURATION

### 3.3.2 CONCLUSION AND KEY POINTS

The previous case studies have defined the ESDC metric and have crystalised the factors determining its value. The following bullet points summarise the findings.

- The ESDCs reflect an energy storage unit's contribution to the security of supply. For example, an ESDC equal to 50% means that the storage unit connected to a load bus can reduce the peak load by 50% of its power capability.
- Calculating the ESDC value can be valuable for network planners. It can inform them about how important the size of the storage unit is (i.e., its power capability expressed in kW) in reducing the peak demand.
- A low ESDC may indicate that the storage unit may not have an optimal power and energy storage ratio, and therefore, it achieves a relatively small peak reduction.
- The ESDC increases as the storage duration increases.
- The ESDC in the system with a peaky load profile is higher than those of relatively flatter profiles.
- The ESDC may reduce or stay the same as the energy storage power capability increases.
- The ESDC can be higher or stay the same with the increase in energy storage efficiency.

# 4. RELIABILITY TESTS FOR FUTURE TRIALS

The studies discussed in section 3 provide insight into the many parameters that can affect the reliability of the EU-SysFlex solutions. Some parameters such as the temporal availability of the service providers or the reliability of the supporting network and control infrastructure and other drivers that may affect the reliability of the solutions (e.g. weather-driven common-mode responses) have to be observed and quantified using real trials. Therefore, reliability analysis can be considered as extended scope of the EU-SysFlex demonstration programme in future.

A list of factors that may affect the reliability performance and the parameters that need to be collected in a set of test system conditions for each type of EU-Sysflex demonstration programme in WP 6- 8 are summarised in the following tables (
Table 4-1 - Table 4-6). The table has the following structure:

- First, it describes the system that provides the grid service(s), the control algorithm, and the description of the flexibility services it offers and the entity that will activate the services.
- Second, It lists some factors that may affect the reliability of the services. These factors may be different from one demo to another demo. The list may not be exhaustive; it provides a starting point and should be extended accordingly when new factors should be considered for quantifying the reliability of the EU-SysFlex services.
- Third, the temporal availability of the individual or aggregated service providers and the deliverability of the services, i.e. the percentage of the planned service volume delivered, should be analysed. Such data will provide insight into the reliability of the services. The services should be observed at the customer point.
- Fourth, a list of test data should be collected considering different system operating conditions (described in the test scenarios). The tests should be carried out long enough to produce sufficient samples to make a robust conclusion. It is worth noting that the reliability of the EU-Sysflex solutions can be affected by different operating conditions that should be identified during the trials.

TABLE 4-1 WP 6 - GERMAN DEMO

| Work package no. 6 | **Demonstration of flexibility services from resources connected to the distribution network / German Demo** |
|---|---|
| The system that provides the service(s) | 2.7 GW wind (HV grid)<br>1 GW PV (HV grid)<br>1.5 GW thermal power plant (HV grid)<br>Aggregated MV resources |
| Control algorithm | - Forecast of load and generation (PV, wind) and state estimation<br>- Forecasts are taken into account for performing grid optimisation and optimising flexibility potentials (loss optimisation, congestion management, local voltage control, contingency analysis)<br>- Aggregation process to inform TSO<br>- Redispatch active and reactive power output |
| Type and a short description of | Management of **active and reactive power injection** from distribution grid (110kV) resources into the transmission grid (380kV and 220kV) for managing congestion and controlling voltages at the transmission |

| | |
|---|---|
| flexibility service(s) | |
| Activation | On-demand by the TSO |
| Factors that may affect reliability | - Availability of wind and PV energy<br>- Forecast error (RES and load forecast)<br>- Distribution network constraints or distribution outages<br>- Interdependency between active and reactive power output<br>- Reliability of the devices, including communication and control infrastructure<br>- The gap period between the commitment and delivery of the service |
| Reliability parameters | - Deliverability of the service<br>- Availability of the service |
| Test data | - The maximum annual capacity of each service from each component relevant for providing the service<br>- The maximum aggregated capacity of each service<br>- The gap period between the commitment and delivery of the service<br><br>For each service and each activation<br>- Timestamp (date and time)<br>- The capacity of the service being committed ahead of real-time from each device / aggregated<br>- Actual available capacity of the service during real-time from each device / aggregated<br>- Expected amount to be delivered from each device / aggregated<br>- The actual amount that is delivered from each device / aggregated<br>- High-level description to describe the reasons if the delivery is not as expected |
| Test scenario | - Test the delivery of each service individually<br>- Test the delivery of multiple simultaneous services<br>- Test the impact of high forecast error of RES/load<br>- Test the impact of distribution circuit/system component outages<br>- Test the impact of communication errors or control errors<br>- Test the impact of different optimisation parameters or risk management |

TABLE 4-2 WP 6 - ITALIAN DEMO

| | |
|---|---|
| Work package no. 6 | **Demonstration of flexibility services from resources connected to the distribution network / Italian Demo** |
| The system that provides the service(s) | 4 PV generators (MV grid)<br>2 OLTCs at HV/MV substation<br>1 MVA/1 MWh battery energy storage system<br>Two 1.2 MVAr STATCOM |
| Control algorithm | An optimisation procedure considering weather forecast and techno-economic constraints to maximise and optimise the involvement of RES and DSO assets for both TSO and DSO needs. The distribution network is optimised to solve congestions and provide optimal setpoints for the assets connected to the distribution network. Distribution network management, monitoring and control process is supported by a central SCADA. |

| Work package no. 6 | **Demonstration of flexibility services from resources connected to the distribution network / Italian Demo** |
|---|---|
| | The reactive power capability calculation, the flexibility aggregation, and the estimation of the maximum reactive power that can be exchanged with the transmission network are performed in the local SCADA.<br>The participating DERs and assets are aggregated at the primary substation level, considering the network constraints. The DSO can manage its assets and other DERs, minimise the dispatching costs, avoid network violations, and generation or load curtailment through optimisation. |
| Type and a short description of flexibility service(s) | -Manage active power flexibility to support **manual frequency restoration reserve/ restoration reserve (mFRR/RR) and congestion management**<br>-Manage reactive power flexibility to support **voltage control & congestion management**<br>The DSO provides these services to the TSO at the TSO/DSO interface. |
| Activation | On-demand by the TSO, DSO network optimisation |
| Factors that affect reliability | - Availability of PV energy<br>- Forecast error (RES forecast)<br>- Consecutive activation of the services (time dependant)<br>- Interdependency between active and reactive power output<br>- Reliability of the devices, including communication and control infrastructure<br>- The gap period between the commitment and delivery of the service<br>- Critical operational emergency context (i.e. weather alert) |
| Reliability parameters | - Deliverability of the service<br>- Availability of the service |
| Test data | - The maximum annual capacity of each service from each component relevant for providing the service<br>- The maximum aggregated capacity of each service<br>- The gap period between the commitment and delivery of the service[4]<br><br>For each service<br>- Timestamp (date and time)<br>- The capacity of the service being committed ahead of real-time from each device / aggregated<br>- Actual available capacity of the service during real-time from each device / aggregated[5]<br>- Expected amount to be delivered from each device / aggregated[6]<br>- The actual amount that is delivered from each device / aggregated<br>- Analyse drivers for the delivery performance (e.g. large forecast error, extreme weather, outages, etc.) |
| Test scenario | - Test the delivery of each service individually<br>- Test the delivery of multiple simultaneous services<br>- Test the impact of high forecast error of RES/load<br>- Test the impact of distribution circuit/system component outages |

[4] The current SCADA system monitors the actual implementation of the command after a trigger of 15'
[5] The trigger for state estimation is about 15'. The implementation of the require set point is in real time.
[6] At present, these information can't be recorded and extracted in a structured way. They are available on demand. Future improvement may be needed.

| Work package no. 6 | **Demonstration of flexibility services from resources connected to the distribution network / Italian Demo** |
|---|---|
| | - Test the impact of communication errors or control errors<br>- Test the impact of different optimisation parameters or risk management |

**TABLE 4-3 WP 6 - FINNISH DEMO**

| Work package no. 6 | **Demonstration of flexibility services from resources connected to the distribution network / Finnish Demo** |
|---|---|
| System that provides the service(s) | The flexible/controllable/distributed assets are:<br>- Industrial scale battery (P and Q)<br>- Office scale battery (P)<br>- Customer scale batteries (P)<br>- EV charging infrastructure (P)<br>- Residential electric storage heating loads with smart meters (P)<br>- PV solar plant (Q) |
| Control algorithm | Small distributed energy resources connected to MV/LV are forecasted, optimised and aggregated, and bids are created for<br>- trading active power (P) to the TSO's marketplace(i.e. provision of ancillary<br>- service to TSO in order for TSO to stabilise frequency in response to<br>- deviations due to normal variations of in production and load)<br>- Optimised use of BESS (i.e. state of charge optimisation)<br>- trading Q in DSO's marketplace in order to balance Q in DSO's grid. |
| Type and a short description of flexibility service(s) | Management of active power and reactive power flexibility to support:<br>- Frequency containment reserve (FCR-N, FCR-D): to stabilise system frequency in response to deviations occurring due to the normal variations in production and consumption<br>- mFRR<br>- voltage control by reactive power support |
| Activation | On-demand by the TSO |
| Factors that affect reliability | The flexible/controllable/distributed assets are:<br>- Battery energy storage system/load forecast error<br>- Heat demand and ambient temperature<br>- Consecutive activation of the services (time dependant)<br>- Reliability of the devices, including communication and control infrastructure<br>- The gap period between the commitment and delivery of the service |
| Reliability parameters | - Deliverability of the service<br>- Availability of the service |
| Test data | - The maximum annual capacity of each service from each component relevant for providing the service<br>- The maximum aggregated capacity of each service<br>- Forecast period<br>- The gap period between the commitment and delivery of the service<br>For each service<br>- Timestamp (date and time)<br>- The capacity of the service being committed ahead of real-time from each device / aggregated<br>- Actual available capacity of the service during real-time from each device / aggregated<br>- Expected amount to be delivered from each device / aggregated |

| | |
|---|---|
| | - The actual amount that is delivered from each device / aggregated<br>- High-level description to describe the reasons if the delivery is not as expected |
| Test scenario | - Test the delivery of each service individually<br>- Test the delivery of multiple simultaneous services<br>- Test the impact of high forecast error of RES/load<br>- Test the impact of distribution circuit/system component outages<br>- Test the impact of communication errors or control errors<br>- Test the impact of different optimisation parameters or risk management |

TABLE 4-4 WP 7 – VPP/PORTUGUESE DEMO

| Work package no. 7 | **Demonstration of a multi-service framework for the coordination of centralised and decentralised flexibilities - VPP/ Portuguese Demo** |
|---|---|
| System that provides the service(s) | VPP uses flexibility provided by<br>1. large-scale variable speed storage pumped hydropower plant 756 MW, i.e. 2x 378MW<br>2. Two wind farms a. 115 MW consisting of 57 turbines, and b. 50 MW consisting of 25 turbines both connected at transmission level |
| Control algorithm | The VPP algorithm forecasts wind/water inflow, prices and, via the optimisation tool, determines the cost-optimal power dispatch schedule for the VPP power generation portfolio (wind farms/ pumped hydro plant). The portfolio is being managed in real-time. |
| Type and a short description of flexibility service(s) | The VPP can access wholesale energy markets (day-ahead/ intraday) and ancillary services market (to provide frequency regulation and balancing reserves: **aFRR + mFRR/RR** provision). |
| Activation | On-demand by the TSO |
| Factors that affect reliability | - Availability of wind energy<br>- RES forecast error<br>- Consecutive activation of the services (time dependant)<br>- Interdependency between arbitrage and balancing services<br>- Reliability of the devices, including communication and control infrastructure<br>- The gap period between the commitment and delivery of the service |
| Reliability parameters | - Deliverability of the service<br>- Availability of the service |
| Test data | - The maximum annual capacity of each service from each component relevant for providing the service<br>- The maximum aggregated capacity of each service<br>- Forecast period<br>- The gap period between the commitment and delivery of the service<br><br>For each service<br>- Timestamp (date and time)<br>- The capacity of the service being committed ahead of real-time from each device / aggregated |

| | |
|---|---|
| | - Actual available capacity of the service during real-time from each device / aggregated<br>- Expected amount to be delivered from each device / aggregated<br>- The actual amount that is delivered from each device / aggregated<br>- High-level description to describe the reasons if the delivery is not as expected |
| Test scenario | - Test the delivery of each service individually<br>- Test the delivery of multiple simultaneous services<br>- Test the impact of high forecast error of RES/load<br>- Test the impact of distribution circuit/system component outages<br>- Test the impact of communication errors or control errors<br>- Test the impact of different optimisation parameters or risk management |

TABLE 4-5 WP 7 – FLEXHUB/PORTUGUESE DEMO

| | |
|---|---|
| Work package no. 7 / Portuguese demo | **Demonstration of a multi-service framework for the coordination of centralised and decentralised flexibilities – FlexHub/ Portuguese Demo** |
| System that provides the service(s) | One TSO/DSO Substation OLTC and two Primary Substations<br>A set of substation Capacitor Banks (two steps of 3,43 Mvar) and<br>Two Wind Farms are connected to a distribution grid. |
| Control algorithm | Based on the needs of the TSO, which will be communicated to the DSO, who owns the Flexihub platform, provision of services is possible based on the optimal use of resources of the DSO. |
| Type and a short description of flexibility service(s) | The **Flexihub** can provide :<br>- provide **reactive power flexibility** to the TSO/DSO interface (for voltage control + congestion management) via a close to real-time continuous intraday local market for Q, from assets connected to the DSO distribution grid.<br>---provide **active power flexibility** to the TSO/DSO interface from assets connected to a distribution grid.<br>--provide **mFRR/RR** reserves through a continuous intraday market. |
| Activation | On-demand by the TSO |
| Factors that affect reliability | - Availability of wind energy<br>- RES forecast error<br>- Interdependency between active power and reactive power services<br>- Reliability of the devices, including communication and control infrastructure<br>- The gap period between the commitment and delivery of the service |
| Reliability parameters | - Deliverability of the service<br>- Availability of the service |
| Test data | - The maximum annual capacity of each service from each component relevant for providing the service<br>- The maximum aggregated capacity of each service<br>- Forecast period<br>- The gap period between the commitment and delivery of the service<br><br>For each service |

| Work package no. 7 / Portuguese demo | **Demonstration of a multi-service framework for the coordination of centralised and decentralised flexibilities – FlexHub/ Portuguese Demo** |
|---|---|
| | - Timestamp (date and time)<br>- The capacity of the service being committed ahead of real-time from each device / aggregated<br>- Actual available capacity of the service during real-time from each device / aggregated<br>- Expected amount to be delivered from each device / aggregated<br>- The actual amount that is delivered from each device / aggregated<br>- High-level description to describe the reasons if the delivery is not as expected |
| Test scenario | - Test the delivery of each service individually<br>- Test the delivery of multiple simultaneous services<br>- Test the impact of high forecast error of RES/load<br>- Test the impact of distribution circuit/system component outages<br>- Test the impact of communication errors or control errors<br>- Test the impact of different optimisation parameters or risk management |

TABLE 4-6 WP 8 – FRENCH DEMO

| Work package no. 8 | **Aggregation Approaches for Multi-services Provision from a Portfolio of Distributed Resources / French demo** |
|---|---|
| System that provides the service(s) | A 12 MW wind farm, 6 x 2000 kW Enercon E82<br>2 MW/ 3 MWh lithium-ion battery<br>PV panels (several kW installed at EDF Concept Grid which have been used to emulate the behaviour of a PV farm of several MW) |
| Control algorithm | - Day-ahead scheduling and intraday rescheduling of energy arbitrage and services allocation for profit maximisation<br>- Intraday adjustment to minimise the impact of deviations due to renewable generation forecast errors and unexpected faults<br>- Local controllers execute the optimised schedule |
| Type and a short description of flexibility service(s) | **FFR:** Ability to increase MW output by an agreed amount for the 2 to 10 second period after the frequency dips below a predefined threshold.<br>Active power output is allowed to dip subsequently, but the extra energy gained during the 2 to 10 s timeframe must be greater than the energy lost during the first 10 seconds of the recovery phase that is relevant when wind turbines provide FFR. When storage provides FFR, the storage state of charge and power limitations must be satisfied.<br>**Frequency containment reserve (FCR)**: Primary reserve activated within 30 seconds and maintained for 15 minutes<br>**Frequency restoration reserve (FRR**): Secondary reserve activated within 5 minutes and maintained for 15 minutes<br>**Ramp-rate control:** Limit the dP/dt of RES output<br>**Peak shaving**: Limit the maximum injection of RES by storing some of the RES output in energy storage<br>**Local voltage control and dynamic reactive response** |

| | |
|---|---|
| | Ability to adjust reactive power output to limit the propagation of voltage drip due to faults |
| Activation | Automatic for the following services: FFR, FCR, FRR<br>Manual activation by TSO |
| Factors that affect reliability | - Reliability of the devices, including communication and control infrastructure<br>- Availability of wind and solar energy<br>- Forecast error (RES forecast, service prices forecast)<br>- Reserves provided by the optimised scheduling or allocation program<br>- Activation of the services previously<br>- The way the contract of the services being setup (flexible/non-flexible)<br>- Interlink between one service to the other services |
| Reliability parameters | - Deliverability of the service<br>- Availability of the service |
| Test data | - The maximum annual capacity of each service from each component relevant for providing the service<br>- The maximum aggregated capacity of each service<br>- Forecast period<br>- The gap period between the commitment and delivery of the service<br><br>For each service<br>- Timestamp (date and time)<br>- The capacity of the service being committed ahead of real-time from each device / aggregated<br>- Actual available capacity of the service during real-time from each device / aggregated<br>- Expected amount to be delivered from each device / aggregated<br>- The actual amount that is delivered from each device / aggregated<br>- High-level description to describe the reasons if the delivery is not as expected |
| Test scenario | - Test the delivery of each service individually<br>- Test the delivery of multiple simultaneous services<br>- Test the delivery of consecutive services<br>- Test the impact of high forecast error of RES<br>- Test the impact of distribution circuit/system component outages<br>- Test the impact of communication errors or control errors<br>- Test the impact of different optimisation parameters or risk management |

The data collected then can be analysed to determine the ESDC matrix indicating the solutions' reliability compared to the traditional solutions.

# 5. SUMMARY

A generic framework has been developed to determine the equivalent service delivering capacity (ESDC) for new emerging services. ESDC is defined as the capacity of traditional service providers that can be replaced by the capacity of the new service providers without compromising system reliability. The framework is tailored to evaluate the reliability metric for DER providing network and balancing services and supply security contribution.

The studies demonstrate that the equivalent capacity from the new resources depends on many factors:

- Temporal availability of the resources – the equivalent capacity becomes higher if the availability of the resources can be improved.
- The number of DER units – a higher number of DER units will increase diversity and capacity contribution.
- Desired confidence level – the higher the number, the lower the capacity contribution can be relied on by the system operator. It will require a trade-off between the cost and reliability performance of the DER services. Allowing low-cost but less reliable DER services may reduce the system costs, although the system operator may need to purchase more services to deal with the less reliable providers. This may require further investigation in future to analyse the costs and benefits of using that approach.
- Local network constraints – they limit DER operation affecting the maximum volume of DER services offered and used by a transmission system operator.
- Common-mode events – these events drive a uniform or identical response from DER units reducing their diversity and reliability performance. For example, extreme cold or hot weather conditions may substantially reduce smart heating systems' availability to support the electricity grid.
- Storage capacity – a higher storage capacity enables DER to provide services for a longer period if needed. DER contribution also depends on the duration of the service required.

By understanding the individual or aggregated reliability performance of DER, the system operator can therefore manage the risk and determine the optimal portfolio of resources considering both conventional and DER. Further work will be required to understand the costs and benefits of using DER flexibility and parameterise the DER reliability. The latter will require trials with a sufficient duration across a full range of plausible operating conditions. A list of factors that may affect the reliability performance and the parameters that need to be collected in a set of test system conditions for each type of EU-Sysflex demonstration programme in WP 6- 8 for future trials are proposed in this report.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under EC-GA No 773505.