Review
of
EREP 130 F Factors

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Contents

1 Introduction

Distribution network security has traditionally relied on conventional network assets such as transformers and circuits to supply energy to consumers from the upstream grid. In recent years, there has been increasing interest in utilising non-network assets to improve cost efficiency and increase security of supply. In particular, Engineering Recommendation (EREC) P2/6 [1], which is the current distribution network planning standard in Great Britain, is a deterministic standard that is largely focused around ensuring that sufficient network redundancy is available to secure demand during peak demand conditions and that loss of supply is recovered within defined timeframes; Distribution Network Operators (DNOs) have a license obligation to plan their systems in accordance with this standard. In this report we explore how EREC P2/6, and the supporting Engineering Report 130 (EREP 130) [2] framework can be revised to update the security contribution assessment for the types of distributed generation now connected to distribution networks and to consider how this approach can be extended to accommodate the characteristics of energy storage and demand side response.

The P2/6 version that was released in 2006, together with EREP 130, extended the existing capacity credit methodology to include distributed generation (DG) resources when assessing a network's security of supply.

Current planning and operation paradigms of electrical distribution networks are facing fundamental challenges:

- The envisaged decarbonisation of the power industry, in which large-scale electrification of transport and heat sectors are expected to play an important role. The key concern is that this development will lead to an increase in electricity demand that may require network reinforcement. In this context, it will be important that the security contribution from distributed generation, demand side response and energy storage is considered alongside traditional network reinforcement, so that the most efficient solution can be implemented.
- The expected widespread deployment of renewables, low-carbon generation and demand technologies, a large proportion of which will be connected to distribution networks, will potentially, for some networks, change the direction of power flows and increase the stress on distribution networks, while also introducing significant additional uncertainty of the demand that needs to be secured.

A new version of Engineering Recommendation P2 [3] has been written and submitted by the Distribution Code Review Panel to Ofgem for approval. This new document, EREC P2/7 differentiates between the level of security that the DNO needs to provide and the means of providing this security. The standard required is set out in EREC P2/7 whilst the means of providing this security is to be set out in the revised version of EREP 130. One of the aims of EREP 130 is to assist network planners in selecting optimal portfolios of network development strategies, including network reinforcement, use of distributed generation, flexible demand, application of energy storage technologies and advanced network technologies to meet the required standard in the most cost-effective way. This is illustrated in Figure 1.

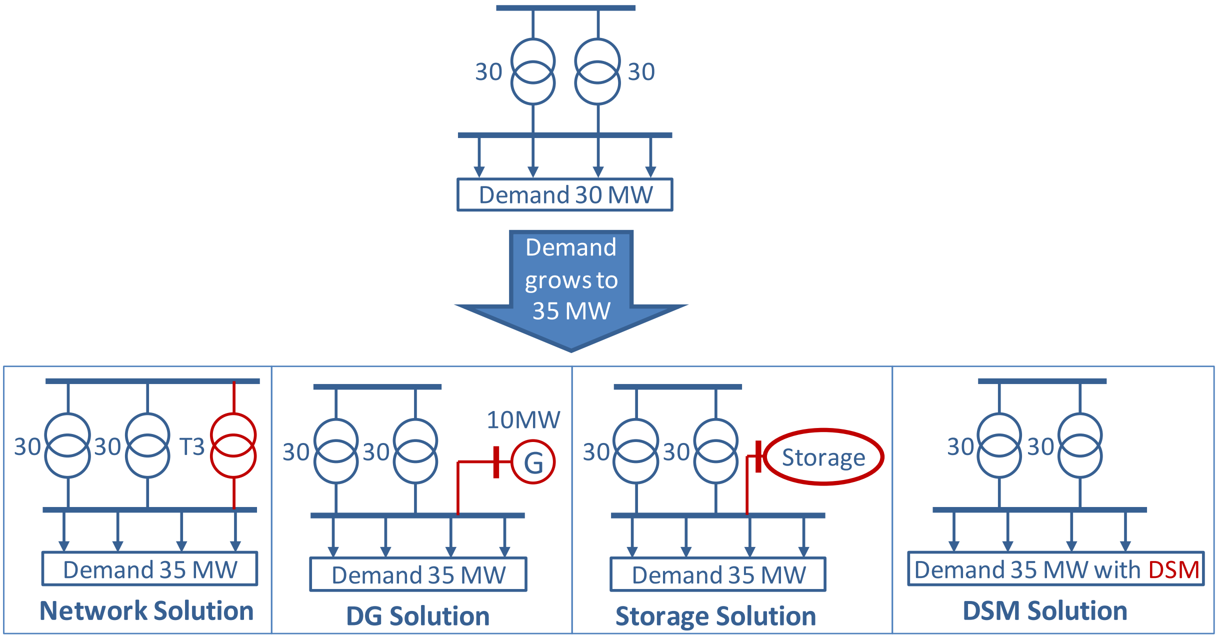

Figure 1: Range of network and non-network solutions for network security problems

Consider the case where a demand of 30MW is secured by two transformers. If the demand grows to 35 MW, network and/or non-network solutions could be considered to secure demand as illustrated in Figure 1.

In order to support the revision of EREP 130, a review and update of the existing DG F Factors currently set out in EREP 130 has been carried out. Furthermore, the F Factors are developed for additional DG technology types that are now connected to distribution networks where there is enough data to undertake the analysis. This review has applied the existing Equivalent Circuit Capacity (ECC) approach as documented in EREP 130 and EREP 131 [4]. In addition, new guidance on how to assess the security contribution from Demand Side Response (DSR) and Electricity Storage (ES) has been developed. For DSR and ES, consideration has been given to extending existing methodology to account for limited capacity of ES and load recovery of DSR. The initial findings from this assessment are included in this report; the results of our further assessment will be presented in a supplementary report.

The output of this project will be used to update the content in ENA EREP 130 to allow DNOs to assess the security contribution offered by DER when assessing compliance with EREC P2/7.

The objectives of the project are as follows:

- Develop tables like the existing Tables 2-1A and 2-1B in EREP 130 for F Factors of non-intermittent types of generation.
- Develop tables like the existing Tables 2-2A and 2-2B in EREP 130 for F Factors of intermittent types of generation.
- Develop table like the existing Table 2-3 in EREP 130 for number of DG units equivalent to First Circuit Outage (FCO) for both non-intermittent and intermittent generation. For non-intermittent generation values might change only if change of F Factors is significant. It should be noted that for intermittent generation the number is always assumed to be 1 in all cases given that the contribution is determined for the complete plant and hence it will remain the same.

- Review whether the Tables 3 and 4 in EREP 130 related to non-intermittent generation in Approach 2 are still appropriate, and develop new tables as required.
- Develop figures like Figures 6.1 and 6.2 in EREP 130 for F Factors of different intermittent generation types as a function of Persistence Tm[1].
- Review, with the ENA EREP 130 WG members/Project Lead, the spreadsheet model referred to in EREP 131 and update guidance in EREP 131 to make the spreadsheet model more accessible to design engineers.
- Provide guidance for assessing security contributions of Demand Side Response (DSR) and Electricity Storage (ES) installations.

New figures are developed for all the DG technology types where there were sufficient amount of data provided by ENA members to undertake the analysis. The following technology types are assessed: biomass, landfill gas, waste, fossil hard coal, fossil oil, hydro run-of-river and poundage, hydro water reservoir, solar, wind offshore, wind onshore, and CHP. The assessment was carried out using the EREP 131 spreadsheet model that was updated as appropriate.

This report contains deliverables 1-6:

- Deliverable 1: Updated ‘EREP 130 Approach 1’ tables,
- Deliverable 2: Updated ‘EREP 130 Approach 2’ non-intermittent DG tables,
- Deliverable 3: Updated ‘EREP 130 Approach 2’ intermittent DG figures.
- Deliverables 4 and 5 EREP 131 spreadsheet and EREP 131 guidance are delivered as separate items.
- Deliverable 6: Guidance on the application of data driven ECC approach to DSR and ES, and corresponding F Factors for DSR and ES calculated by data driven approach where data are available.

The supplementary report contains deliverable 7:

- Deliverable 7: Guidance on the application of modelling approach for security contribution of DSR and ES (fully consistent with the ECC framework) and F Factors for agreed parameters.

The report contains the following sections:

- Section 2 describes obtained data and data gap analysis.
- Section 3 shows the updated DG F Factors i.e. Deliverables 1 to 3.
- Section 4 provides an initial review of the assessment of the security contribution from ES and DSR i.e. Deliverable 6.
- Section 5 provides reference for updated EREP 131 spreadsheet and EREP 131 guidance.
- Section 6 lists references.

[1] For generation to provide security, the output must remain at or above a certain required level for a minimum duration defined as Tm. This is generally only a problem with intermittent generation such as wind due to its significant variability. This persistence time has a considerable impact on the capability that can be associated with intermittent generation and is related to the duration of the system conditions for which such generation may be able to avoid or reduce customer disconnections. There are three distinct system conditions, each of which can be associated with different minimum persistence times. These are switching, repair and maintenance activities.

2 Data Collection and Data Gap Analysis

The following data was obtained from the EREP 130 WG:

- Declared Net Capability[2] (DNC) and a set of annual historical half-hourly profiles of non-intermittent types of generating plants.
- DNC and a set of annual historical half-hourly profiles of intermittent types of generating plant.
- A set of annual half-hourly load profiles for distribution networks supplying different geographical areas and voltage levels. The load profiles are derived from substations with the normal operating condition of the network.
- Historical half-hourly profile import and export profiles of ES.

The generation and demand data received covered the period from 2013 to 2018. A set of normalised annual demand profiles for different regions (from rural to urban areas) were also received. All profiles are based on 30-minute resolution. To relate more to the seasonal security assessment that DNOs carry out, winter and summer are both defined as four months starting on 1 November and from 1 May respectively. Data gap analysis was carried out and the following was performed in order to improve data quality:

- A few of significantly lower, compared to the peak output, onshore wind and hydro DG generation DNCs were adjusted where plausible e.g. where data was incorrectly recorded by the DNO. Where it was not plausible, data sets were eliminated e.g. part of annual export profile was unrealistically high while the other part was realistic.
- Removed empty data from start and the end of data set. For example, generation data was provided for the full timestamp range, but the corresponding load profile was not. In that case, load data was assumed to start from the first non-blank value.
- Data sets covering less than a complete season were not considered.
- Where a small number of data points were missing, these were estimated using historical data
- Where the load profile had a significant proportion of missing data, that particular season was omitted from the analysis.
- For some generation data, one or two days (timestamps) were missing or clearly incorrect. This was ignored, given that if all seasonal data is included there is no effect on the F Factor calculation for persistence level of 0.5 hours and minimal or no effect on other persistence levels.
- For some generation data, timestamps were missing for some days (e.g. one to four days in June). Subsequent days are used for calculation of summer F Factors.

A DG plant capacity factor, defined as the ratio of the plant actual output over a period, to its potential output if operated at full DNC continuously over the same period, is a key driver of DG contribution to security of supply, particularly for non-intermittent generation. Figure 2 shows distribution of capacity factor for winter and summer seasons. Winter season is assumed to start on 1 November and end on 28 February. Summer season is assumed to start on 1 May and end on 31 August.

[2] Per definition in EREP 130

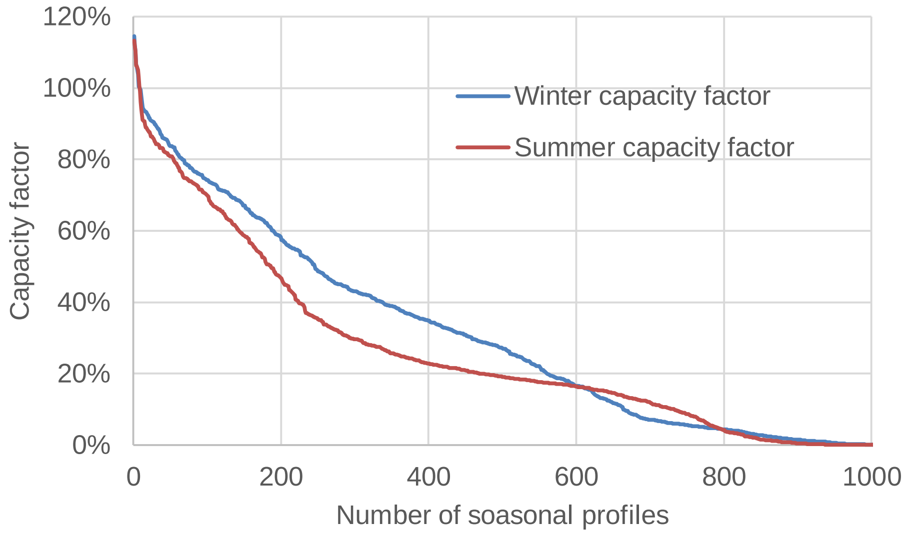

Figure 2. Distribution of capacity factor. Winter season: 1 Nov – 28 Feb; Summer season: 1 May – 31 Aug.

To better understand impact of capacity factor on DG F Factors, the results of F Factor analysis, based on EREP 131, are split in five groups based on range of capacity factors as shown in Table 1. The capacity factor below 2% is not considered in order to exclude DG plant where the output was zero and plant during test / commissioning phases. In the presented results, headline values represent the range of capacity factors.

Table 1. Range of capacity factors.

Range (%)	Headline value (%)
2 – 20	10
20 – 40	30
40 – 60	50
60 – 80	70
80 – max	90

Capacity factors across multiple years are analysed and results are shown in Table 2 and Table 3 for a selection of non-intermittent generation types. Table 2 contains generators for which the capacity factor is relatively stable year on year while Table 3 contains generators for which the capacity factor changes more than 20% year on year. There are more generators where the capacity factor is relatively stable, within available data, year on year capacity factor. There are also significant number of generators where year on year capacity factors are different. This is important in order to assign the right level of contribution to security of supply which could realistically be expected to be delivered year on year. It should be noted that in some instances capacity factor is greater than 1 but this is the result from the obtained plant profile and DNC, and indicates some data issues.

Table 2. Generators for which capacity factor is relatively stable year on year

Technology Type	Generator Ref Nº	Winter Capacity Factors	Summer Capacity Factors
Biomass	3	0.32, 0.29, 0.26	0.28, 0.21, 0.18
Biomass	5	0.36, 0.29, 0.32	0.17, 0.18, 0.14
Biomass	6	0.02, 0.02, 0	0, 0.03, 0.06
Biomass	83	0.81, 0.92	0.76, 0.86
Biomass	666	0.28, 0.37, 0.43, 0.37, 0.37	0.34, 0.38, 0.46, 0.43, 0.3
Biomass	669	0.78, 0.8, 0.81	0.69, 0.75, 0.77
Biomass	865	0.73, 0.85, 0.81, 0.83	0.75, 0.84, 0.82, 0.82
Landfill Gas	38	0.2, 0.22, 0.21	0.2, 0.22, 0.21
Landfill Gas	41	0.63, 0.57, 0.48	0.54, 0.52, 0.43
Landfill Gas	42	0.43, 0.32, 0.36	0.37, 0.3, 0.31
Landfill Gas	43	0.16, 0.14, 0.12	0.15, 0.13, 0.11
Landfill Gas	658	1.05, 1.11, 1.1, 1.08	1.13, 1.14, 1.12, 1.1
Landfill Gas	713	0.8, 0.8, 0.81, 0.74, 0.68	0.79, 0.82, 0.79, 0.76, 0.67
Landfill Gas	717	0.12, 0.05, 0.02, 0.02, 0.01	0.11, 0.16, 0.04, 0.01, 0.01
Landfill Gas	718	0.63, 0.7, 0.7, 0.56, 0.5	0.6, 0.58, 0.66, 0.63, 0.53
Landfill Gas	727	0.56, 0.56, 0.53, 0.48, 0.47	0.54, 0.58, 0.56, 0.53, 0.43
Waste	30	0.8, 0.84, 0.89	0.78, 0.69, 0.65
Waste	652	0.6, 0.62, 0.67, 0.72, 0.6	0.49, 0.62, 0.64, 0.68, 0.64
Waste	659	0.78, 0.75, 0.77, 0.76, 0.74	0.72, 0.72, 0.71, 0.67, 0.66
Waste	667	0.75, 0.7, 0.75, 0.78, 0.8	0.76, 0.77, 0.8, 0.79, 0.75
Waste	726	0.57, 0.67, 0.56, 0.64, 0.67	0.5, 0.35, 0.53, 0.39, 0.48
Waste	729	0.58, 0.59, 0.62, 0.63, 0.63	0.47, 0.46, 0.41, 0.49, 0.51
Waste	730	0.54, 0.6, 0.61, 0.61, 0.55	0.47, 0.54, 0.5, 0.49, 0.51
Waste	763	0.12, 0.21, 0.14	0.04, 0.19, 0.18
Waste	912	0.61, 0.46, 0.63, 0.58	0.46, 0.51, 0.54, 0.55

Table 3. Generators for which capacity factors change for more than 20% year on year

Technology Type	Generator Ref Nº	Winter Capacity Factors	Summer Capacity Factors
Biomass	1	0.91, 0.72, 0.45	0.68, 0.42, 0.64
Biomass	2	0.32, 0.85	0.74, 0.56
Biomass	4	0.67, 0.88	0.71, 0.81
Biomass	733	0.66, 0.8, 1.12, 1.15, 1.1	0.39, 0.78, 1.1, 1.12, 1.08
Biomass	868	0.88, 0.79, 0.77, 0.75	0.52, 0.82, 0.79, 0.78
Biomass	759	0.11, 0.55, 0.83, 0.86, 0.55	0.03, 0.49, 0.67, 0.69, 0.59
Biomass	768	0.31, 0.26, 0.48, 0.73, 0.49	0.26, 0.17, 0.38, 0.63, 0.53
Biomass	770	0.62, 0.56, 0.53, 0.43, 0.29	0.35, 0.61, 0.62, 0.52, 0.48
Biomass	773	0.46, 0.88, 0.84, 0.86	0.48, 0.69, 0.91, 0.82
Biomass	775	0.99, 1.01, 0.95, 0.88, 0.8	0.34, 0.96, 1.03, 0.97, 0.64
Landfill Gas	39	0.85, 0.74, 0.56	0.82, 0.62, 0.58
Landfill Gas	40	0.83, 0.75, 0.58	0.75, 0.66, 0.54
Landfill Gas	655	0.94, 0.91, 0.87, 0.89, 0.73	0.87, 0.87, 0.83, 0.8, 0.65

Technology Type	Generator Ref Nº	Winter Capacity Factors	Summer Capacity Factors
Landfill Gas	1014	0.5, 0.9, 0.91	0, 0.9, 0.87
Waste	27	0.77, 0.56	0.55, 0.63
Waste	29	0.72, 0.06, 0.81	0.69, 0.73, 0.49
Waste	32	0.78, 0.5, 0.31	0.85, 0.24, 0.5
Waste	753	0.45, 0.73, 0.72, 0.69, 0.81	0.58, 0.78, 0.55, 0.67, 0.7
Waste	1146	0.47, 0.59	0.27, 0.56
Waste	1147	0.25, 0.61	0.13, 0.74

To illustrate different capacity factors year on year, below are examples of profiles for some of the generator cases from Table 3 as shown in Figure 3, Figure 4 and Figure 5.

As shown in Figure 3, generation output for more than a year is about half what was generated during the previous period. It is likely only half of the plant operated during this period.

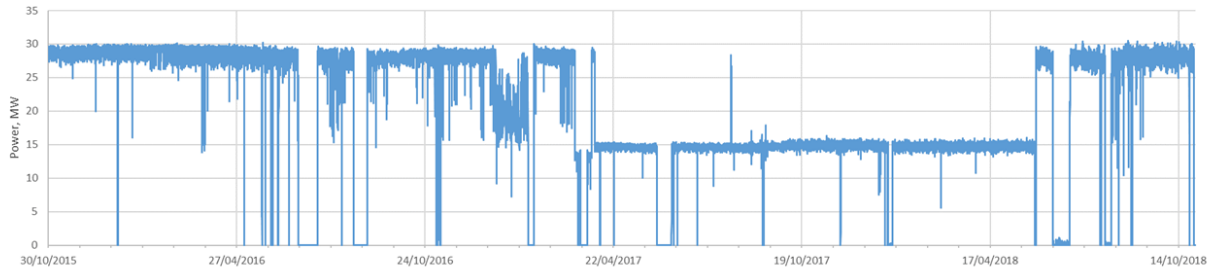

Figure 3. Generator case 1: For a more than a year generating output is about half.

In Figure 4, generation output for about half of winter 2016/17 is zero or close to zero. In addition, there are two periods during which generation increases broadly from zero to about 3 MW, but they do not occur at the same time of year.

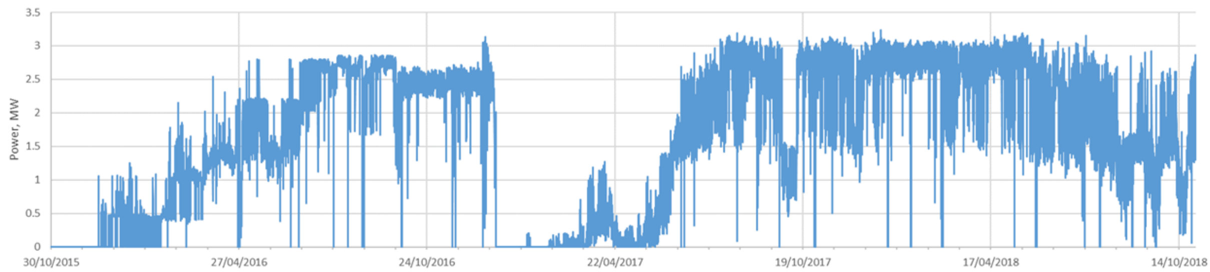

Figure 4. Generator case 2: For about half of winter 2016/17, generation output is very low

In Figure 5, generation output is zero for considerate period during 2016/17. In addition, a lower output is observed during summer 2018. This could be due to the generation being out of service or a problem with the data recorder.

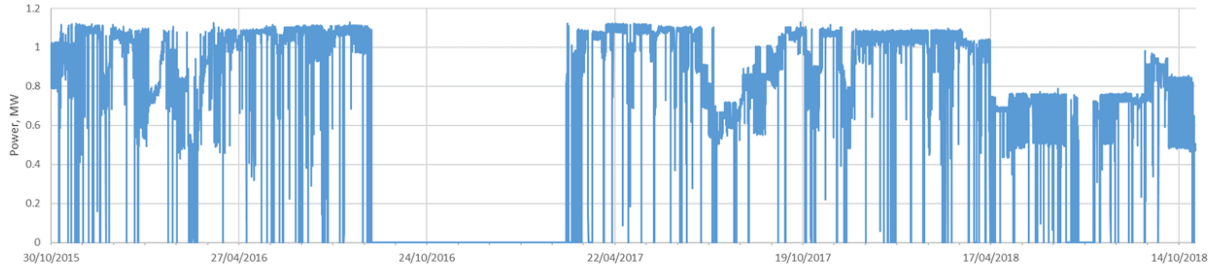

Figure 5. Generator case 29: A period during which generation output is zero. In addition, the profile is very variable with output being zero from time to time.

The above figures illustrate different, and potentially significant, variability of some of the received generation profiles which drives different year on year capacity factors. Historical generation operating patterns for existing generators should be considered to establish the suitable capacity factor. For new connected generators suitable capacity factors could be potentially established based on data from generation already connected which could be revised once the actual generation profiles become available.

3 Distributed Generation F Factors

3.1 Approach

The ECC approach is used for quantifying security of supply contribution of DG plants, which is illustrated in Figure 6. In this approach, the network is not included in the analysis, and the demand profile/load duration curve is normalised to the power capacity of Non-Network Solution (NNS) such that peak demand is equal to the NNS power capacity. Within this approach, the value of the risk indicator (in EREC P2/6 'expected energy not supplied' is the risk indicator used) for a portion of demand (D_Y) supplied from NNS facilities, excluding network circuits is calculated. Then the NNS is replaced with an ideal, 100% reliable, source ECC and the capacity of the ECC calculated such that the value of risk indicator (expected energy not supplied) remains the same. The NNS contribution to security of supply is the capacity of the ideal source ECC. The contribution of the NNS facilities is independent of the network reliability performance. Statistical analysis of F Factors is carried out providing their average and standard deviation values which are used to estimate the robustness of results.

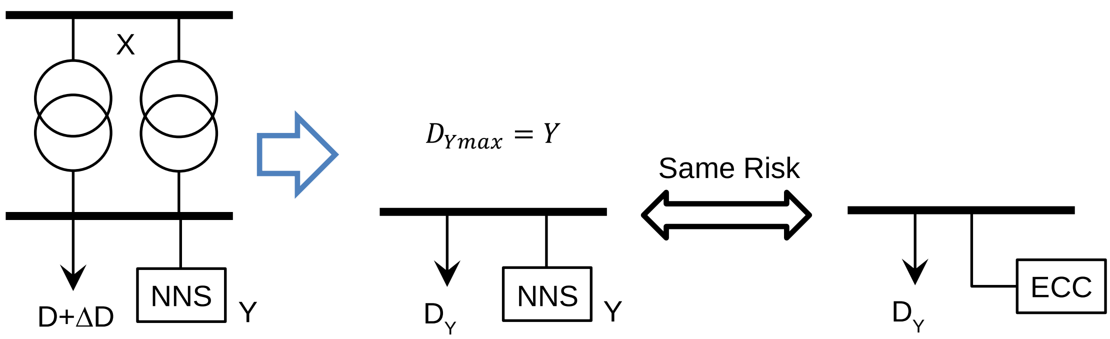

Figure 6. Illustration of ECC approach

The obtained generation output and demand profile data is prepared and entered in the EREP 131 spreadsheet and F Factors calculated for the different generation technology types and seasons. For intermittent generation, F Factors are calculated also for different persistence durations. This analysis included also generation with onsite demand.

3.2 Non-intermittent Distributed Generation

Table 4 shows statistical parameters of annual F Factors for non-intermittent DG types for different technology types. For each technology type the number of calculations / cases analysed, average, minimum, maximum and standard deviation of F Factors are provided. A significant range of F Factors is observed. For example, for biomass, the observed F Factors range from 4-81% with average value of 46% and standard deviation of 19%. For Biomass, Landfill Gas and Waste technology type, enough data was available that provided statistically robust estimates of the security factors. For other technology types, it was considered that there were an insufficient number of cases for the data to be statistically robust.

Table 4. Annual statistical parameters of F Factors for non-intermittent DG

Technology Type	Number	F Factor (%)			
		Average	Min	Max	St Dev
Biomass	75	46%	4%	81%	19%
CHP	14	23%	6%	49%	17%
Fossil Gas	27	17%	2%	63%	20%
Fossil Oil	7	33%	4%	55%	19%
Gas	10	24%	3%	40%	16%
Marine - Tidal	3	11%	6%	19%	7%
Mixed	27	38%	4%	73%	22%
Other Generation	13	10%	3%	17%	5%
Other, CHP	69	23%	3%	69%	21%
Landfill Gas	74	48%	4%	78%	21%
Waste	70	47%	4%	71%	14%

Statistical parameters of seasonal F Factors are shown in Table 5. The observed range of DG F Factors is relatively wide.

Table 5. Seasonal statistical parameters of F Factors for non-intermittent DG

Technology Type	Winter					Summer				
	Number	Average	Min	Max	St Dev	Number	Average	Min	Max	St Dev
Biomass	76	52%	4%	86%	22%	75	46%	4%	83%	21%
CHP	13	29%	4%	60%	22%	14	25%	6%	55%	16%
Fossil Gas	31	17%	2%	70%	20%	19	25%	2%	82%	29%
Fossil Oil	8	33%	5%	56%	22%	6	44%	5%	83%	25%
Gas	11	24%	3%	49%	19%	9	25%	7%	39%	13%
Geothermal	2	4%	3%	4%	1%					
Marine - Tidal	3	16%	8%	29%	11%	2	15%	7%	23%	11%
Mixed	27	38%	5%	79%	26%	26	42%	2%	81%	22%
Other Generation	17	9%	2%	18%	6%	12	10%	4%	17%	5%
Other, CHP	62	27%	2%	80%	24%	63	26%	3%	75%	23%
Landfill Gas	74	51%	3%	83%	23%	73	50%	4%	100%	23%
Waste	71	54%	2%	82%	19%	69	48%	5%	78%	16%

Further analysis was carried out to split the results per capacity factor to reduce the above range of F Factors. Table 6 shows statistical parameters of F Factors for non-intermittent generation for different capacity factors and seasons. Capacity factor is defined as the ratio of the plant actual output over a period, to its potential output if operated at full DNC continuously over the same period. F Factor results for capacity factors between 2 to 20% are grouped under a headline value of 10% quoted in the table. Other groups are 20-40%, 40-60%, 60-80% and above 80%. Results for F Factors are given for different seasons.

Table 6. F Factors of non-intermittent generation for different capacity factors and seasons

Capacity Factor	Winter Number	Winter Average	Winter Min	Winter Max	Winter St Dev	Summer Number	Summer Average	Summer Min	Summer Max	Summer St Dev
Biomass										
90%	22	76%	64%	86%	6%	15	72%	61%	83%	7%
70%	20	60%	42%	78%	11%	18	58%	30%	77%	12%
50%	11	45%	32%	57%	9%	19	42%	30%	55%	7%
30%	18	30%	23%	37%	4%	12	32%	28%	36%	3%
10%	5	7%	4%	14%	4%	11	13%	4%	20%	7%
Other, Landfill Gas										
90%	22	74%	50%	83%	7%	21	72%	53%	100%	10%
70%	14	65%	41%	75%	9%	14	66%	43%	78%	9%
50%	15	51%	43%	57%	4%	13	54%	42%	58%	4%
30%	12	29%	20%	36%	6%	14	29%	11%	40%	8%
10%	11	13%	3%	19%	5%	11	13%	4%	19%	4%
Waste										
90%	7	73%	64%	82%	6%	4	71%	60%	78%	8%
70%	39	64%	40%	75%	7%	26	59%	44%	72%	8%
50%	14	50%	37%	58%	7%	26	45%	36%	54%	5%
30%	5	26%	22%	28%	3%	8	31%	22%	36%	4%
10%	6	7%	2%	15%	5%	5	14%	5%	20%	6%

Knowing the capacity factor for a particular DG would increase confidence in the calculated F Factor as the standard deviations in Table 6 are relatively lower than in Table 5. For example, winter average and standard deviation of F Factor for biomass generation type is 52% and 22%, respectively (Table 5). Depending on capacity factor the average F Factor is between 7% and 76% and standard deviation is between 4% and 11%. The standard deviation is improved but the number of cases is reduced e.g. for Biomass generation type with 10% capacity factor class during winter season there are only 5 cases; the reduced number of cases means that the results are less statistically robust. As mentioned above, there is also the risk that a given DG plant will not have a consistent capacity factor (and hence F Factor) year on year.

3.3 Intermittent Distributed Generation

Table 7 shows the number of cases analysed for intermittent renewables DG types per capacity factor and season.

Table 7. Number of cases of intermittent renewables DG types

Season	Capacity factor 10%	30%	50%	70%
Onshore wind				
Winter	48	109	34	3
Summer	96	97	3	
Offshore wind				
Winter	3	15	16	
Summer	6	26	1	
Solar				
Winter	100			
Summer	78	25		

Capacity factors for many onshore wind farms are within the 20%-40% range (30%) during the winter season and within the 2%-20% range (10%) and the 20%-40% range (30%) during the summer season.

Many capacity factors of offshore wind farms are within the 20%-40% range (30%) and the 40%-60% range (50%) during the winter season and within the 20%-40% range (30%) for the summer season.

Capacity factor of solar plants are within the 2%-20% range (10%) for the winter season while during the summer some are around the 20%-40% range (30%).

Whilst there are differences between capacity factors, the average F Factors are presented for all plants. If appropriate, the spreadsheet approach (EREP 131) could be used to obtain more accurate results for a specific plant.

Table 8 shows the number of calculation cases of intermittent renewables DG types per capacity factor and season.

Table 8. Number of cases of intermittent hydro DG types

Season	Capacity factor 10%	30%	50%	70%	90%
Hydro run-of-river and poundage					
Winter	3	11	12	5	
Summer	18	8	2		
Hydro water reservoir					
Winter	36	31	25	12	2
Summer	67	28	1	3	

Many hydro run-of-river and poundage plant capacity factors are within the 20%-40% range (30%) and the 40%-60% range (50%) capacity factor during winter and within the range 2%-20% (10%) during summer season.

Capacity factors of a significant number of hydro water reservoir plant are within 10%, 30% and 50% bands during winter and within 10% and 30% bands during summer season.

Whilst there are differences between capacity factors, the average F Factors are presented for all plants. As capacity factors for intermittent generation are less variable than for non-intermittent generation the rest of the analysis is not broken down by capacity factor.

Table 9 shows F Factors statistics for intermittent renewables DG types for different season and persistence level.

Table 9. F Factors for intermittent renewables DG types

Technology Type	Season	Values	Persistence, h 0.5	2	3	6	12	18	24	48	120	360	480
Onshore wind	Winter	Average (%)	26	24	24	22	19	16	14	9	4	3	3
		Min (%)	6	6	5	5	4	3	2	1	1	1	1
		Max (%)	59	58	57	56	54	52	48	38	18	16	16
		St Dev (%)	9	9	8	8	8	7	7	5	2	2	2
	Summer	Average (%)	19	18	17	15	13	11	9	6	3	3	3
		Min (%)	5	5	4	4	3	2	2	1	1	1	1
		Max (%)	40	38	37	35	31	28	27	26	22	18	14
		St Dev (%)	6	6	6	6	5	5	5	4	3	2	1
Offshore wind	Winter	Average (%)	32	31	30	29	26	23	20	13	6	4	4
		Min (%)	6	5	5	4	4	3	2	1	1	1	1
		Max (%)	51	49	48	46	43	40	37	26	19	19	18
		St Dev (%)	10	10	10	10	9	8	8	6	4	3	3
	Summer	Average (%)	24	23	22	20	17	15	13	8	4	3	3
		Min (%)	3	2	2	2	1	1	1	1	1	1	1
		Max (%)	35	34	33	31	30	30	29	28	25	20	12
		St Dev (%)	8	7	7	7	6	6	6	5	4	3	2
Solar[3]	Winter	Average (%)	6	6	5	4	2	2	2	2	2	2	2
		Min (%)	3	3	3	2	1	1	1	1	1	1	1
		Max (%)	13	12	12	10	5	5	5	4	4	4	4
		St Dev (%)	2	2	2	1	1	1	1	1	0	0	0
	Summer	Average (%)	16	15	14	12	5	2	2	2	2	2	2
		Min (%)	3	3	3	2	1	1	1	1	1	1	1
		Max (%)	22	22	21	20	9	3	3	3	3	3	3
		St Dev (%)	4	4	4	3	2	0	0	0	0	0	0

F Factors for onshore wind farms are greater during winter season, e.g. for persistence of 0.5 hours average F Factors are 26% and 19% for winter and summer season, respectively. Average F Factors reduce as persistence increases and for a persistence of 24 hours average F Factors are broadly half of value for a persistence of 0.5 hours. A significant variability of F Factors is observed e.g. between 6% and 59% for winter season and a persistence of 0.5 hours. Standard deviation is 9% (35% of average value) for winter season and a persistence of 0.5 hours. For a persistence level of 24 hours, standard deviation drops to 7% (47% of average value).

F Factors for offshore wind farms follow similar pattern except that average F Factors are greater than for onshore wind farms.

If desired, the spreadsheet approach (EREP 131) could be used to more accurately calculate F Factors of a specific wind farm.

F Factors for solar plants are more than 2.5-fold greater during summer season, e.g. 16% compared to winter 6% for persistence of 0.5 hours. The ECC approach results in a low F

[3] It is not expected to rely on Solar generation for 18 or more hours even though for persistence time of 18 hours or more average F Factors are greater than zero.

Factors for 18 or more hours although it is not considered reasonable to rely on the security contribution from solar generation for 18 or more hours. Generally, a wide range of F Factors is observed even though the standard deviation is relatively moderate compared to wind farms. It is important to stress that the ECC concept for F Factors does not explicitly consider peak demand periods. In this context this methodology does not take into account the fact that demand peaks in winter would normally occur during evening period when solar plants would not generate. In this case, it would be appropriate to assume that F Factors for solar plant would be zero for winter season (in some cases this may apply for summer season too).

Table 10 shows F Factors statistics for intermittent hydro DG types for different seasons and persistence levels.

Table 10. F Factors for intermittent hydro DG types

Technology Type	Season	Values	Persistence, h										
			0.5	2	3	6	12	18	24	48	120	360	480
Hydro run-of-river and poundage	Winter	Average (%)	36	36	35	35	34	33	31	28	21	10	9
		Min (%)	6	6	6	6	6	5	5	4	2	1	1
		Max (%)	74	74	74	74	74	74	73	73	69	56	52
		St Dev (%)	17	17	17	17	17	17	16	16	16	13	12
	Summer	Average (%)	17	17	16	16	15	14	13	11	8	3	3
		Min (%)	3	3	2	1	1	1	1	1	1	1	1
		Max (%)	41	41	41	41	41	41	40	39	33	12	8
		St Dev (%)	10	10	9	9	9	9	9	9	7	3	2
Hydro water reservoir	Winter	Average (%)	29	29	28	27	26	23	22	21	18	12	10
		Min (%)	4	4	4	2	1	1	1	1	1	1	1
		Max (%)	76	76	76	75	74	72	70	70	68	60	56
		St Dev (%)	17	17	18	18	19	19	19	18	16	13	12
	Summer	Average (%)	16	16	15	14	13	12	11	10	9	6	5
		Min (%)	3	3	3	3	2	1	1	1	1	1	1
		Max (%)	70	70	70	70	70	69	69	67	61	52	52
		St Dev (%)	11	11	11	12	12	12	12	12	11	8	7

Significant difference between seasonal average F Factors for hydro type generation is observed, e.g. 36% during winter compared to 17% during summer for hydro run-of-river and poundage and for persistence of 0.5 hours. It can be observed that the range of F Factors is significant. Furthermore, the observed standard deviation is relatively large compared with other renewables DG types, which was expected given the range of capacity factors. However, the F Factors are more stable, with increase of persistence when compared with F Factors for other renewable DG types.

Figure 7 shows average winter season F Factors for intermittent DG types for different persistence levels. These values are the same as F Factors for winter presented in Table 9 and Table 10.

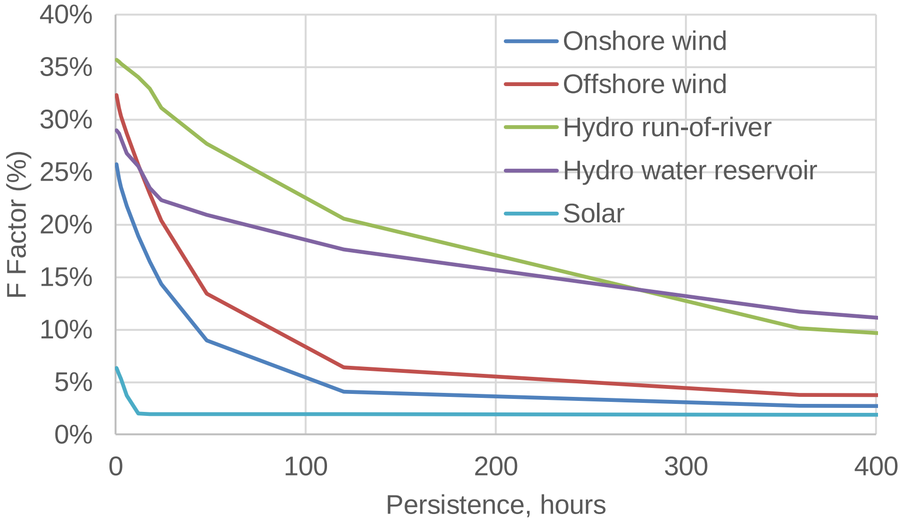

Figure 7. Average winter season F Factors of intermittent DG types for different persistence levels

Figure 8 shows average summer season F Factors for intermittent DG types for different persistence levels. These values are the same as F Factors for summer presented in Table 9.

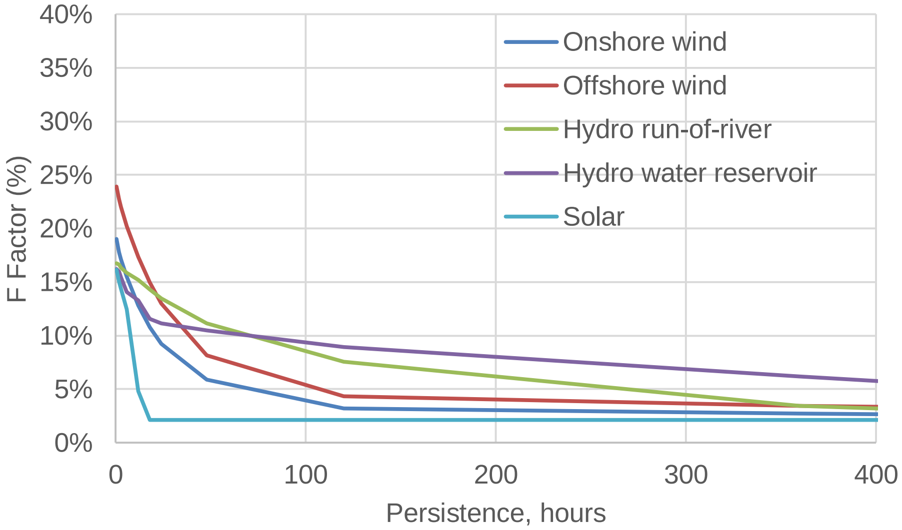

Figure 8. Average summer season F Factors of intermittent DG types for different persistence levels

As expected, F Factors are greater in summer season for solar generation while for the other generation types F Factors are greater in winter season.

Table 11 shows the intermittent renewables DG type F Factors for different geographical areas, seasons and persistence levels. North represents Scotland, South represents South West, Southern England, South East and London DNO licence areas. Middle represents the remaining DNO licence areas.

Table 11. Statistical parameters of F Factors of intermittent renewables DG types for different geographical location, season and persistence level.

Type	Season	Location	Values	Persistence, h 0.5	2	3	6	12	18	24	48	120	360	480
Onshore wind	Winter	North	Average (%)	28	26	25	24	21	18	16	10	4	3	3
			St Dev (%)	5	5	5	5	4	4	3	3	1	1	1
		Middle	Average (%)	25	23	23	21	18	16	14	8	4	3	3
			St Dev (%)	9	9	8	8	8	7	6	4	3	2	2
		South	Average (%)	29	28	27	25	22	20	17	11	5	3	3
			St Dev (%)	12	12	12	12	12	12	11	9	4	1	1
	Summer	North	Average (%)	20	18	17	16	13	10	9	5	3	2	2
			St Dev (%)	6	6	5	5	4	4	3	2	0	0	0
		Middle	Average (%)	19	18	17	16	13	11	9	6	3	3	3
			St Dev (%)	6	6	6	5	5	5	5	4	3	3	2
		South	Average (%)	17	16	16	14	12	10	8	5	3	2	2
			St Dev (%)	9	8	8	8	7	6	6	3	1	0	0
Offshore wind	Winter	Middle	Average (%)	35	34	33	31	28	25	22	15	7	4	4
			St Dev (%)	8	8	8	8	7	7	7	5	4	4	3
		South	Average (%)	22	21	20	19	17	15	13	8	4	2	2
			St Dev (%)	12	12	11	11	10	9	8	5	3	1	1
	Summer	Middle	Average (%)	27	25	25	23	19	17	15	9	5	4	3
			St Dev (%)	5	5	5	5	5	5	5	5	4	4	2
		South	Average (%)	14	13	13	12	10	8	7	5	3	2	2
			St Dev (%)	7	7	7	6	5	4	4	2	1	1	1
Solar[4]	Winter	North	Average (%)	5	5	4	3	2	2	2	2	2	2	2
			St Dev (%)	1	1	1	1	0	0	0	0	0	0	0
		Middle	Average (%)	6	5	5	4	2	2	2	2	2	2	2
			St Dev (%)	2	2	2	2	1	1	1	1	1	0	0
		South	Average (%)	7	6	6	4	2	2	2	2	2	2	2
			St Dev (%)	1	1	1	1	1	0	0	0	0	0	0
	Summer	North	Average (%)	14	13	12	10	4	2	2	2	2	2	2
			St Dev (%)	6	5	5	4	2	1	1	1	1	1	1
		Middle	Average (%)	15	14	13	11	4	2	2	2	2	2	2
			St Dev (%)	4	4	4	4	2	1	1	1	1	1	1
		South	Average (%)	18	17	16	14	5	2	2	2	2	2	2
			St Dev (%)	3	3	3	2	1	0	0	0	0	0	0

For onshore wind, there is no significant difference between average value of F Factors in North and South regions during winter period. F Factors for Middle region is a bit lower compared to the other two regions e.g. average value, for persistence of 0.5 hours, is 25% compared to 28% or 29%. For summer season a small trend could be observed with greater values of F Factors in North regions.

For offshore wind, differences between average values of F Factors are more significant, in both winter and summer seasons, with greater F Factors for Middle compared to South region, e.g. in winter average F Factor in Middle region is 35% while in South 22% for persistence of 0.5 hours. No offshore wind data was available for North region.

[4] It is not expected to rely on Solar generation type for 18 or more hours even though for persistence times of 18 hours or more average F Factors are greater than zero.

Average summer F Factors for solar generation are greater in South region e.g. 14% or 15% in North and Middle regions, respectively compared to 18% in South region for persistence of 0.5 hours. During the winter period, average F Factors are significantly lower compared to the summer period, but geographical difference is not as significant. As indicated earlier, the established F Factor methodology does not consider the fact that peak demand in winter would normally occur during evening period when solar plants would not generate and hence it may be appropriate not to consider capacity contribution of solar plants.

Table 12 shows the intermittent hydro DG type F Factors for different geographical areas, seasons and persistence levels.

Table 12. Statistical parameters of F Factors of intermittent hydro DG types for different geographical location, season and persistence level.

Type	Season	Location	Values	Persistence, h										
				0.5	2	3	6	12	18	24	48	120	360	480
Hydro run-of-river and poundage	Winter	North	Average (%)	27	27	27	26	25	24	23	19	12	5	5
			St Dev (%)	10	10	10	10	10	10	10	9	8	5	4
		Middle	Average (%)	41	41	41	41	40	39	36	33	26	13	11
			St Dev (%)	18	18	18	18	18	18	18	18	18	15	14
	Summer	North	Average (%)	18	18	17	17	16	14	13	10	6	3	3
			St Dev (%)	9	9	9	9	9	8	8	7	6	3	2
		Middle	Average (%)	16	16	16	15	15	14	14	12	9	3	3
			St Dev (%)	10	10	10	10	10	10	10	10	9	3	2
Hydro water reservoir	Winter	North	Average (%)	38	38	37	35	34	33	32	31	28	19	18
			St Dev (%)	16	16	16	17	18	19	19	19	17	13	13
		Middle	Average (%)	26	26	25	24	23	20	20	18	15	10	8
			St Dev (%)	17	17	17	18	18	19	18	18	16	12	11
		South	Average (%)	33	32	32	31	29	28	25	23	19	13	11
			St Dev (%)	19	19	19	19	19	19	17	17	17	12	11
	Summer	North	Average (%)	28	28	27	26	25	24	23	22	20	14	13
			St Dev (%)	21	21	22	22	23	23	23	22	20	15	14
		Middle	Average (%)	14	14	14	12	11	9	9	8	7	5	4
			St Dev (%)	6	6	7	7	7	7	7	7	6	5	3
		South	Average (%)	12	11	11	10	10	9	8	7	5	3	3
			St Dev (%)	5	5	4	4	4	4	4	3	2	1	1

For hydro run-of-river and poundage data was available for North and Middle regions. Greater average values of F Factors are observed for winter season and Middle region, e.g. 41%, for persistence of 0.5 hours, compared to 27% (North, winter), 18% (North, summer) and 16% (Middle, summer). It can be seen that in summer the geographical difference between F Factors is not significant.

Average values of F Factors for hydro water reservoir are greater in North region in both winter and summer periods e.g. 38% compared to 33% for South and 26% for Middle regions in winter period and persistence of 0.5 hours. Considering only South and Middle regions, in winter average F Factors are greater in South region compared to Middle region, e.g. 33% compared to 26% for persistence of 0.5 hours, while in summer these are greater in Middle region compared to South region, e.g. 14% compared to 12% for persistence of 0.5 hours.

Table 13 shows the number of cases analysed for intermittent renewables DG types for different geographical areas and seasons.

Table 13. Number of cases for intermittent renewables DG types for different geographical areas and seasons

Season	North	Middle	South
Onshore wind			
Winter	33	140	21
Summer	33	141	21
Offshore wind			
Winter		27	7
Summer		26	7
Solar			
Winter	7	48	45
Summer	9	49	45

A statistically significant amount of data was available for Middle region for onshore wind, i.e. 140 generation-year for winter and 141 for summer period, followed by solar, 48 and 49 for winter and summer periods, respectively. An adequate amount of data was available also for onshore wind in north region, 33 for both winter and summer periods, and solar in south region, 45 for both regions.

Table 14 shows the number of cases analysed for intermittent hydro DG types for different geographical areas and seasons.

Table 14. Number of cases for intermittent hydro DG types for different geographical areas and seasons

Season	North	Middle	South
Hydro run-of-river and poundage			
Winter	12	19	
Summer	12	16	
Hydro water reservoir			
Winter	16	73	17
Summer	16	70	13

A statistically significant amount of data was available for Middle region for hydro water reservoir, i.e. 73 and 70 generation-year for winter and summer periods, respectively.

3.4 Number of DG units equivalent to a First Circuit Outage

EREP 130 WG advised that DNOs assessment of DG security contribution is conducted using DG plant profiles as more reliable data is available for this approach rather than making an assessment on the number of plant generating units, the unit rating and availability. Given this, it is proposed that the output of all DG units (i.e. the DG facility), rather than individual units, is considered as equivalent to a First Circuit Outage (FCO). In the current version of EREP 130 Issue 2 [2], this approach is applied to intermittent generation only. Consequently, it was agreed that there is no need to provide an update of Table 2-3 nor Table 4 in EREP 130.

3.5 Generic approach

To derive Table 3 of EREP 130 Issue 2 [2], generic unit availability and a typical load duration curve are used, as described in Developing P2/6 Methodology report [5]. For Table 4 of EREP 130 Issue 2, generic unit availability is used to calculate the number of units equivalent to FCO. The generic approach could still be used if the detailed availability data was available, however, if demand and generation profiles are available for a specific site, it would be appropriate to use the EREP 131 spreadsheet and directly calculate corresponding F Factors.

4 Guidance for Calculation of F Factors of DSR and ES

An aspect of the project was to consider whether it would be possible to apply the F Factor approach to assess the security contribution from demand side response and energy storage. Two approaches were considered:

a) data driven approach based on import and export profile data available from DNOs, as per the DG assessment

b) a modelling approach.

4.1 Data driven approach

The initial thought was that DSR and ES security contribution could be established by the ECC approach if import and export profiles were available from the plant. The same approach applied for intermittent generation would be applicable. However, ENA members were only able to provide one example of an ES profile; no examples of DSR were available. The security contribution of the ES example for different persistence levels were calculated and presented to EREP 130 WG. However, given that there was only one example this is not statistically robust and to keep anonymity the results are not reproduced in this report; the assessment did however demonstrate that the methodology used for assessing the security contribution for DG could be used for ES where an export profile is available.

4.2 Modelling Approach for Calculation of F Factors of ES

A modelling approach for calculation of DSR and ES security contribution based on a transparent analytical time-series based approach for peak minimisation by controlling of DSR and ES operation was considered. This approach follows the shift generation F Factor calculation paradigm [6] taking explicitly into account electrical energy related DSR and ES constraints. It also considers likelihood of DSR operational performance, DSR load recovery effect, ability to recharge ES from upstream network, availability of ES, DSR coincidence in delivery and interaction between DSR and ES as appropriate. To inform development of this analytical approach, the results are compared with outputs of our tool based on Monte Carlo simulation that was used in Smarter Network Storage project for quantifying ECC based security contribution of Leighton Buzzard ES.

The proposed analytical approach will be described in more detail in a supplementary report.

5 Update of EREP 131 Spreadsheet and EREP 131 Application Guidance

The requirements of the spreadsheet and application guidance in order to be more accessible to design engineers is clarified with the EREP 130 working group. In addition, within this project the spreadsheet tool is updated for the calculation of F Factors. This includes profile-based specification of demand and calculation of DSR F Factors. The updated EREP 131 guidance and spreadsheet are in addition to this report.

6 References

[1] Electricity Networks Association, Engineering Recommendation P2/6: Security of Supply, 2006.
[2] ENA, Engineering Report 130, Application guide for assessing the capacity of networks containing distributed generation, Issue 2 2014.
[3] ENA, DCRP/18/03/PC - Revision to Engineering Recommendation P2 - Security of Supply, 2018.
[4] ENA, Engineering reports 131, analysis package for assessing generation security capability – Users' Guide and Attachment, Issue 2, 2012.
[5] R. Allan, G. Strbac, P. Djapic, K. Jarrett, Developing the P2/6 Methodology, UMIST, 2004.
[6] British Electricity Boards, Report on the Application of Engineering recommendation P2/5 Security of Supply, A.C.E. Report No. 51 (1979).