Annexes

A Commission Regulation (EU) 2016/631

This annex shows the articles defined by the European commission that applies to this project: **COMMISSION REGULATION (EU) 2016/631 of 14 April 2016** establishing a network code on requirements for grid connection of generators. These contents have been introduced in the following for the sake of completeness.

Article 5: Determination of significance, it is checked that the type of power-generating is the Type C. In addition, the synchronous area is Continental Europe:

2. Power-generating modules within the following categories shall be considered as significant:

(c) connection point below 110 kV and maximum capacity at or above a threshold specified by each relevant TSO in accordance with paragraph 3 (type C). This threshold shall not be above the limits for type C power-generating modules contained in Table 1; or

Limits for thresholds for type B, C and D power-generating modules

Synchronous areas	Limit for maximum capacity threshold from which a power-generating module is of type B	Limit for maximum capacity threshold from which a power-generating module is of type C	Limit for maximum capacity threshold from which a power-generating module is of type D
Continental Europe	1 MW	50 MW	75 MW
Great Britain	1 MW	50 MW	75 MW
Nordic	1,5 MW	10 MW	30 MW
Ireland and Northern Ireland	0,1 MW	5 MW	10 MW
Baltic	0,5 MW	10 MW	15 MW

Article 15: General requirements for type C power-generating modules

1. Type C power-generating modules shall fulfil the requirements laid down in Articles 13 and 14, except for Article 13(2)(b) and (6) and Article 14(2).

2. Type C power-generating modules shall fulfil the following requirements relating to frequency stability:

(a) with regard to active power controllability and control range, the power-generating module control system shall be capable of adjusting an active power setpoint in line with instructions given to the power-generating facility owner by the relevant system operator or the relevant TSO.

The relevant system operator or the relevant TSO shall establish the period within which the adjusted active power setpoint must be reached. The relevant TSO shall specify a tolerance (subject to the availability of the prime mover resource) applying to the new setpoint and the time within which it must be reached;

(b) manual local measures shall be allowed in cases where the automatic remote control devices are out of service. The relevant system operator or the relevant TSO shall notify the regulatory authority of the time required to reach the setpoint together with the tolerance for the active power; 27.4.2016 EN Official Journal of the European Union L 112/21

(c) In addition to Article 13(2), the following requirements shall apply to type C power-generating modules with regard to limited frequency sensitive mode — underfrequency (LFSM-U):

(i) the power-generating module shall be capable of activating the provision of active power frequency response at a frequency threshold and with a droop specified by the relevant TSO in coordination with the TSOs of the same synchronous area as follows:

— the frequency threshold specified by the TSO shall be between 49,8 Hz and 49,5 Hz inclusive,

— the droop settings specified by the TSO shall be in the range 2-12 %.

This is represented graphically in Figure 4;

(ii) the actual delivery of active power frequency response in LFSM-U mode shall take into account:

— ambient conditions when the response is to be triggered,

— the operating conditions of the power-generating module, in particular limitations on operation near maximum capacity at low-frequencies and the respective impact of ambient conditions according to paragraphs 4 and 5 of Article 13, and

— the availability of the primary energy sources.

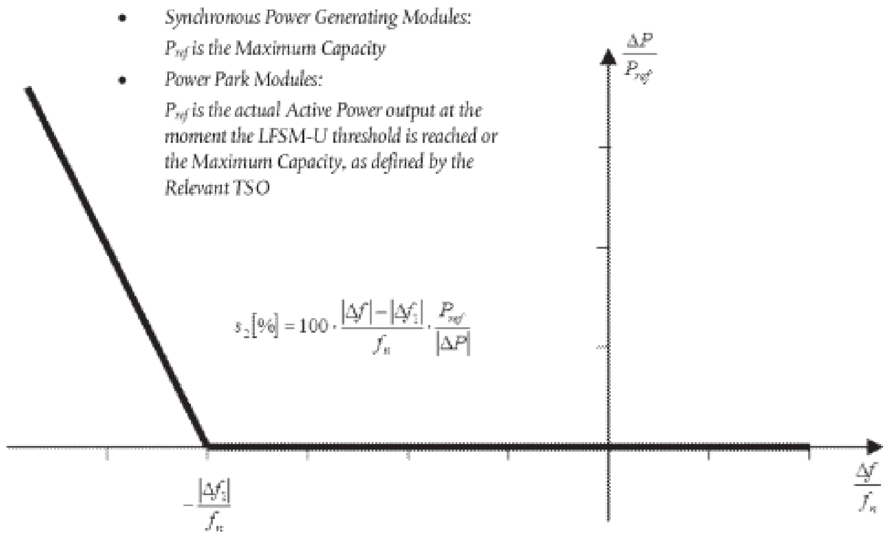
(iii) the activation of active power frequency response by the power-generating module shall not be unduly delayed. In the event of any delay greater than two seconds, the power-generating facility owner shall justify it to the relevant TSO;

(iv) in LFSM-U mode the power-generating module shall be capable of providing a power increase up to its maximum capacity;

(v) stable operation of the power-generating module during LFSM-U operation shall be ensured;

Figure 4

Active power frequency response capability of power-generating modules in LFSM-U



Pref is the reference active power to which ΔP is related and may be specified differently for synchronous power-generating modules and power park modules. ΔP is the change in active power output from the power-generating module. fn is the nominal frequency (50 Hz) in the network and Δf is the frequency deviation in the network. At underfrequencies where Δf is below Δf1 the power-generating module has to provide a positive active power output change according to the droop S2.

(d) in addition to point (c) of paragraph 2, the following shall apply cumulatively when frequency sensitive mode ('FSM') is operating:

(i) the power-generating module shall be capable of providing active power frequency response in accordance with the parameters specified by each relevant TSO within the ranges shown in Table 4. In specifying those parameters, the relevant TSO shall take account of the following facts:

— in case of overfrequency, the active power frequency response is limited by the minimum regulating level,

— in case of underfrequency, the active power frequency response is limited by maximum capacity,

— the actual delivery of active power frequency response depends on the operating and ambient conditions of the power-generating module when this response is triggered, in particular limitations on operation near maximum capacity at low-frequencies according to paragraphs 4 and 5 of Article 13 and available primary energy sources;

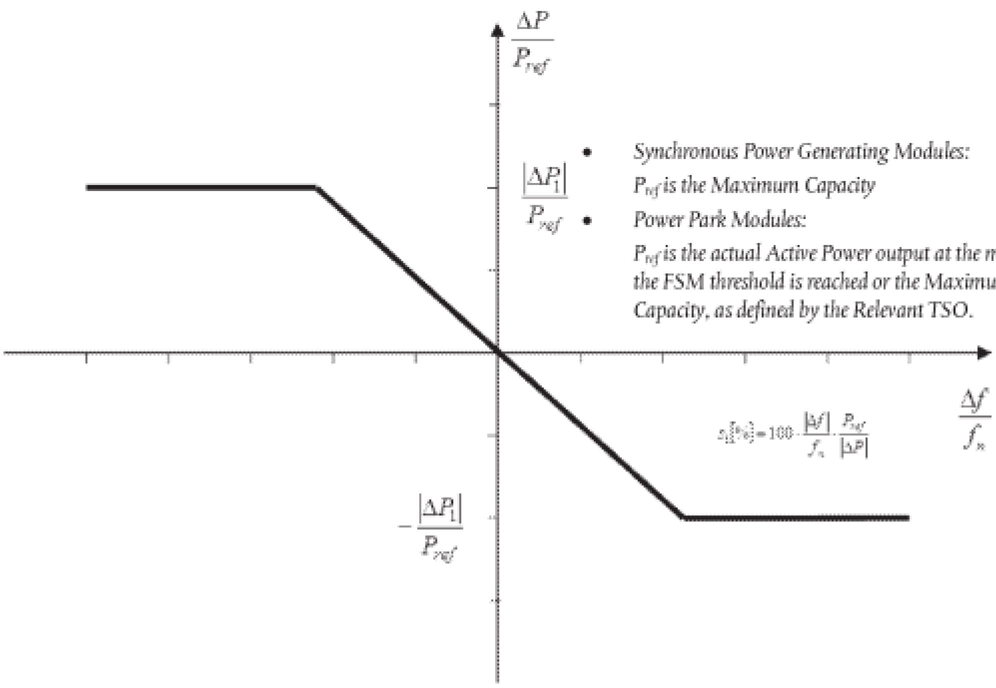
Table 4

Parameters for active power frequency response in FSM (explanation for Figure 5)

Parameters		Ranges
Active power range related to maximum capacity $\frac{\lvert\Delta P_1\rvert}{P_{max}}$		1,5-10 %
Frequency response insensitivity	$\lvert\Delta f_i\rvert$	10-30 mHz
	$\frac{\lvert\Delta f_i\rvert}{f_n}$	0,02-0,06 %
Frequency response deadband		0-500 mHz
Droop s_1		2-12 %

Figure 5

Active power frequency response capability of power-generating modules in FSM illustrating the case of zero deadband and insensitivity



Pref is the reference active power to which ΔP is related. ΔP is the change in active power output from the power-generating module. fn is the nominal frequency (50 Hz) in the network and Δf is the frequency deviation in the network.

(ii) the frequency response deadband of frequency deviation and droop must be able to be reselected repeatedly;

(iii) in the event of a frequency step change, the power-generating module shall be capable of activating full active power frequency response, at or above the full line shown in Figure 6 in accordance with the parameters specified by each TSO (which shall aim at avoiding active power oscillations for the power-generating module) within the ranges given in Table 5. The combination of choice of the parameters specified by the TSO shall take possible technology-dependent limitations into account;

(iv) the initial activation of active power frequency response required shall not be unduly delayed.

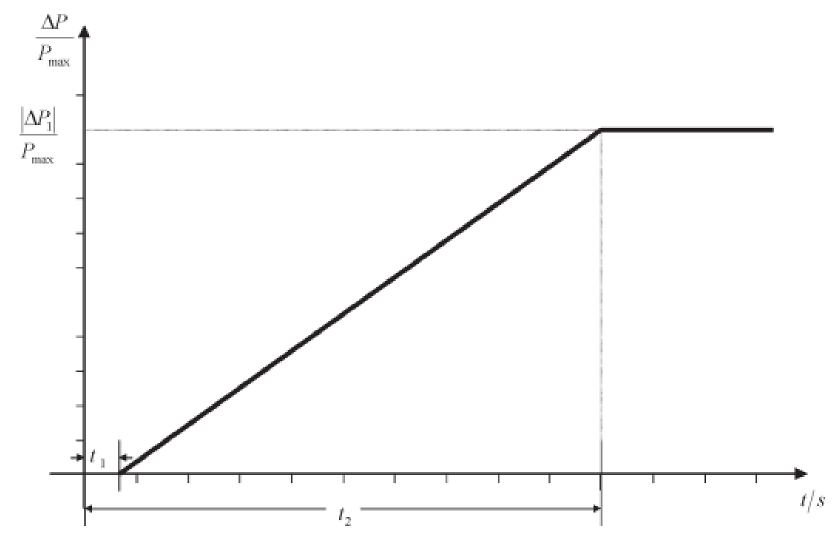
If the delay in initial activation of active power frequency response is greater than two seconds, the power-generating facility owner shall provide technical evidence demonstrating why a longer time is needed.

For power-generating modules without inertia, the relevant TSO may specify a shorter time than two seconds.

If the power-generating facility owner cannot meet this requirement they shall provide technical evidence demonstrating why a longer time is needed for the initial activation of active power frequency response;

Figure 6

Active power frequency response capability



Pmax is the maximum capacity to which ΔP relates. ΔP is the change in active power output from the power-generating module. The power-generating module has to provide active power output ΔP up to the point ΔP1 in accordance with the times t1 and t2 with the values of ΔP1, t1and t2 being specified by the relevant TSO according to Table 5. t1 is the initial delay. t2 is the time for full activation.

(v) the power-generating module shall be capable of providing full active power frequency response for a period of between 15 and 30 minutes as specified by the relevant TSO. In specifying the period, the TSO shall have regard to active power headroom and primary energy source of the power-generating module;

(vi) within the time limits laid down in point (v) of paragraph 2(d), active power control must not have any adverse impact on the active power frequency response of power-generating modules; L 112/24 EN Official Journal of the European Union 27.4.2016

(vii) the parameters specified by the relevant TSO in accordance with points (i), (ii), (iii) and (v) shall be notified to the relevant regulatory authority. The modalities of that notification shall be specified in accordance with the applicable national regulatory framework;

Table 5

Parameters for full activation of active power frequency response resulting from frequency step change (explanation for Figure 6)

Parameters	Ranges or values
Active power range related to maximum capacity (frequency response range) $\frac{\lvert \Delta P_1 \rvert}{P_{max}}$	1,5-10 %
For power-generating modules with inertia, the maximum admissible initial delay t_1 unless justified otherwise in line with Article 15(2)(d)(iv)	2 seconds
For power-generating modules without inertia, the maximum admissible initial delay t_1 unless justified otherwise in line with Article 15(2)(d)(iv)	as specified by the relevant TSO.
Maximum admissible choice of full activation time t_2, unless longer activation times are allowed by the relevant TSO for reasons of system stability	30 seconds

(e) with regard to frequency restoration control, the power-generating module shall provide functionalities complying with specifications specified by the relevant TSO, aiming at restoring

frequency to its nominal value or maintaining power exchange flows between control areas at their scheduled values;

(f) with regard to disconnection due to underfrequency, power-generating facilities capable of acting as a load, including hydro pump-storage power-generating facilities, shall be capable of disconnecting their load in case of underfrequency.

The requirement referred to in this point does not extend to auxiliary supply;

(g) with regard to real-time monitoring of FSM:

(i) to monitor the operation of active power frequency response, the communication interface shall be equipped to transfer in real time and in a secured manner from the power-generating facility to the network control centre of the relevant system operator or the relevant TSO, at the request of the relevant system operator or the relevant TSO, at least the following signals:

— status signal of FSM (on/off),

— scheduled active power output,

— actual value of the active power output,

— actual parameter settings for active power frequency response,

— droop and dead band;

(ii) the relevant system operator and the relevant TSO shall specify additional signals to be provided by the power-generating facility by monitoring and recording devices in order to verify the performance of the active power frequency response provision of participating power-generating modules.

3. With regard to voltage stability, type C power-generating modules shall be capable of automatic disconnection when voltage at the connection point reaches levels specified by the relevant system operator in coordination with the relevant TSO.

The terms and settings for actual automatic disconnection of power-generating modules shall be specified by the relevant system operator in coordination with the relevant TSO.

4. Type C power-generating modules shall fulfil the following requirements relating to robustness:

(a) in the event of power oscillations, power-generating modules shall retain steady-state stability when operating at any operating point of the P-Q-capability diagram;

(b) without prejudice to paragraph 4 and 5 of Article 13, power-generating modules shall be capable of remaining connected to the network and operating without power reduction, as long as voltage and frequency remain within the specified limits pursuant to this Regulation;

(c) power-generating modules shall be capable of remaining connected to the network during single-phase or three-phase auto-reclosures on meshed network lines, if applicable to the network to which they are connected. The details of that capability shall be subject to coordination and agreements on protection schemes and settings as referred to in point (b) of Article 14(5).

5. Type C power-generating modules shall fulfil the following requirements relating to system restoration:

(a) with regard to black start capability:

(i) black start capability is not mandatory without prejudice to the Member State's rights to introduce obligatory rules in order to ensure system security;

(ii) power-generating facility owners shall, at the request of the relevant TSO, provide a quotation for providing black start capability. The relevant TSO may make such a request if it considers system security to be at risk due to a lack of black start capability in its control area;

(iii) a power-generating module with black start capability shall be capable of starting from shutdown without any external electrical energy supply within a time frame specified by the relevant system operator in coordination with the relevant TSO;

(iv) a power-generating module with black start capability shall be able to synchronise within the frequency limits laid down in point (a) of Article 13(1) and, where applicable, voltage limits specified by the relevant system operator or in Article 16(2);

(v) a power-generating module with black start capability shall be capable of automatically regulating dips in voltage caused by connection of demand;

(vi) a power-generating module with black start capability shall:

— be capable of regulating load connections in block load,

— be capable of operating in LFSM-O and LFSM-U, as specified in point (c) of paragraph 2 and Article 13(2),

— control frequency in case of overfrequency and underfrequency within the whole active power output range between minimum regulating level and maximum capacity as well as at houseload level,

— be capable of parallel operation of a few power-generating modules within one island, and

— control voltage automatically during the system restoration phase;

(b) with regard to the capability to take part in island operation:

(i) power-generating modules shall be capable of taking part in island operation if required by the relevant system operator in coordination with the relevant TSO and:

— the frequency limits for island operation shall be those established in accordance with point (a) of Article 13(1),

— the voltage limits for island operation shall be those established in accordance with Article 15(3) or Article 16(2), where applicable;

(ii) power-generating modules shall be able to operate in FSM during island operation, as specified in point (d) of paragraph 2.

In the event of a power surplus, power-generating modules shall be capable of reducing the active power output from a previous operating point to any new operating point within the P-Q-capability diagram. In that regard, the power-generating module shall be capable of reducing active power output as much as inherently technically feasible, but to at least 55 % of its maximum capacity;

(iii) the method for detecting a change from interconnected system operation to island operation shall be agreed between the power-generating facility owner and the relevant system operator in coordination with the relevant TSO. The agreed method of detection must not rely solely on the system operator's switchgear position signals;

(iv) power-generating modules shall be able to operate in LFSM-O and LFSM-U during island operation, as specified in point (c) of paragraph 2 and Article 13(2);

(c) with regard to quick re-synchronisation capability:

(i) in case of disconnection of the power-generating module from the network, the power-generating module shall be capable of quick re-synchronisation in line with the protection strategy agreed between the relevant system operator in coordination with the relevant TSO and the power-generating facility;

(ii) a power-generating module with a minimum re-synchronisation time greater than 15 minutes after its disconnection from any external power supply must be designed to trip to house-load from any operating point in its P-Q-capability diagram. In this case, the identification of house-load operation must not be based solely on the system operator's switchgear position signals;

(iii) power-generating modules shall be capable of continuing operation following tripping to house-load, irrespective of any auxiliary connection to the external network. The minimum operation time shall be specified by the relevant system operator in coordination with the relevant TSO, taking into consideration the specific characteristics of prime mover technology.

6. Type C power-generating modules shall fulfil the following general system management requirements:

(a) with regard to loss of angular stability or loss of control, a power-generating module shall be capable of disconnecting automatically from the network in order to help preserve system security or to prevent damage to the power-generating module. The power-generating facility owner and the relevant system operator in coordination with the relevant TSO shall agree on the criteria for detecting loss of angular stability or loss of control;

(b) with regard to instrumentation:

(i) power-generating facilities shall be equipped with a facility to provide fault recording and monitoring of dynamic system behaviour. This facility shall record the following parameters:

— voltage,

— active power,

— reactive power, and

— frequency.

The relevant system operator shall have the right to specify quality of supply parameters to be complied with on condition that reasonable prior notice is given;

(ii) the settings of the fault recording equipment, including triggering criteria and the sampling rates shall be agreed between the power-generating facility owner and the relevant system operator in coordination with the relevant TSO;

(iii) the dynamic system behaviour monitoring shall include an oscillation trigger specified by the relevant system operator in coordination with the relevant TSO, with the purpose of detecting poorly damped power oscillations;

(iv) the facilities for quality of supply and dynamic system behaviour monitoring shall include arrangements for the power-generating facility owner, and the relevant system operator and the relevant TSO to access the information. The communications protocols for recorded data shall be agreed between the power-generating facility owner, the relevant system operator and the relevant TSO; 27.4.2016 EN Official Journal of the European Union L 112/27

(c) with regard to the simulation models:

(i) at the request of the relevant system operator or the relevant TSO, the power-generating facility owner shall provide simulation models which properly reflect the behaviour of the

power-generating module in both steadystate and dynamic simulations (50 Hz component) or in electromagnetic transient simulations.

The power-generating facility owner shall ensure that the models provided have been verified against the results of compliance tests referred to in Chapters 2, 3 and 4 of Title IV, and shall notify the results of the verification to the relevant system operator or relevant TSO. Member States may require that such verification be carried out by an authorised certifier;

(ii) the models provided by the power-generating facility owner shall contain the following sub-models, depending on the existence of the individual components:

— alternator and prime mover,

— speed and power control,

— voltage control, including, if applicable, power system stabiliser ('PSS') function and excitation control system,

— power-generating module protection models, as agreed between the relevant system operator and the power-generating facility owner, and

— converter models for power park modules;

(iii) the request by the relevant system operator referred to in point (i) shall be coordinated with the relevant TSO. It shall include:

— the format in which models are to be provided,

— the provision of documentation on a model's structure and block diagrams,

— an estimate of the minimum and maximum short circuit capacity at the connection point, expressed in MVA, as an equivalent of the network;

(iv) the power-generating facility owner shall provide recordings of the power-generating module's performance to the relevant system operator or relevant TSO if requested. The relevant system operator or relevant TSO may make such a request, in order to compare the response of the models with those recordings;

(d) with regard to the installation of devices for system operation and devices for system security, if the relevant system operator or the relevant TSO considers that it is necessary to install additional devices in a power-generating facility in order to preserve or restore system operation or security, the relevant system operator or relevant TSO and the power-generating facility owner shall investigate that matter and agree on an appropriate solution;

(e) the relevant system operator shall specify, in coordination with the relevant TSO, minimum and maximum limits on rates of change of active power output (ramping limits) in both an up

and down direction of change of active power output for a power-generating module, taking into consideration the specific characteristics of prime mover technology;

(f) earthing arrangement of the neutral-point at the network side of step-up transformers shall comply with the specifications of the relevant system operator [30] [31].

B MATLAB code

Annex B contain the main MATLAB codes used to treat data and to calculate several results from the wind park. Data collection and treatment, as said in the document, needs to follow the time step of the GAMS simulation (15 s step) since are going to be used for the optimization as well as WP results from MATLAB. Here are explained and shown 6 MATLAB codes.

1. Treatment of Frequency data: Next code shows for one of the months (February in this case). The data from the National Grid UK website was downloaded in an Excel file and later it was needed to be read and kept in a .mat file for future uses in other codes:

```
% Read National Grid UK data
data_2 = csvread('f 2016 2.csv', 1, 1);
var2 = data_2(:,1)';


i=1;
for x=1:15:length(var1)-1
    freq_january_15(i)=var1(x);
    i=i+1;
end
freq_january_15;
```

2. Data from REE was downloaded in a Excel file and pasted to a .mat file. Here can be checked how the data was treated to obtain the steps for the simulation program every 15 s called in this code as *intra_market_15s* and defined in the document for the GAMS simulation as $\lambda_{m,t}$.

```
% Read and treatment of REE data
load REE_data.mat
j=1;
k=1;
x=1;
for x=1:length(REE_data)
      for i=[1:240]
          intra_market_15secs(k)=REE_data(j);
          k=k+1;
      end
      j=j+1;
      x=x+1;
end
intra_market_15secs;
```

3. Then, it has been calculated the power the WP can generate with no PRIMARY FREQUENCY CONTROL limitations. Every month is calculated the same. Here are shown the wind speed of the month and how to extrapolate it to have variations every 15 s, the Cp from Gamesa manufacturer for different wind speeds, and the Power generation of one WT considering the wind speed variations at a high precision (0.01 m/s variations) and the respective Cp. Due to the data is from an array it was not possible to minimize the code creating a for loop so, here is shown a code of long extension.

At the end if this code, it is shown how it was restricted the power generated of the WT (due to the maximum has to be 4.5 MW) and it was referred in the document previously as E_{max} for the GAMS simulation.

```
% January 2017
load v_sodar_january.mat
v_january=0; % the wind speed every 15 s in January (m/s)
j=1;
for i=1:length(v_sodar_january)-1
      v_january(j)=-((v_sodar_january(i+1)-v_sodar_january(i))/(2-1))*(2-
1)+v_sodar_january(i+1);
      v_january(j+1)=-((v_sodar_january(i+1)-v_sodar_january(i))/(2-1))*(2-
1.25)+v_sodar_january(i+1);
      v_january(j+2)=-((v_sodar_january(i+1)-v_sodar_january(i))/(2-1))*(2-
1.5)+v_sodar_january(i+1);
      v_january(j+3)=-((v_sodar_january(i+1)-v_sodar_january(i))/(2-1))*(2-
1.75)+v_sodar_january(i+1);
      j=j+4;
end
v_january;

% Cp from the manufacturer G120-4.5MW
Cp=[0.280 0.390 0.430 0.450 0.460 0.460 0.460 0.440 0.390 0.330 0.260 0.210
0.170 0.140 0.120 0.100 0.090 0.080 0.070 0.065 0.040 0.030 0.025 0.020
0.020];
Cp_f=0;
j=1;
for i=1:length(Cp)-1
Cp_f(j)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1)+Cp(i+1);
Cp_f(j+1)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.05)+Cp(i+1);
Cp_f(j+2)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.1)+Cp(i+1);
Cp_f(j+3)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.15)+Cp(i+1);
Cp_f(j+4)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.2)+Cp(i+1);
Cp_f(j+5)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.25)+Cp(i+1);
Cp_f(j+6)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.3)+Cp(i+1);
Cp_f(j+7)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.35)+Cp(i+1);
Cp_f(j+8)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.4)+Cp(i+1);
Cp_f(j+9)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.45)+Cp(i+1);
Cp_f(j+10)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.5)+Cp(i+1);
Cp_f(j+11)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.55)+Cp(i+1);
Cp_f(j+12)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.6)+Cp(i+1);
Cp_f(j+13)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.65)+Cp(i+1);
Cp_f(j+14)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.7)+Cp(i+1);
Cp_f(j+15)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.75)+Cp(i+1);
Cp_f(j+16)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.8)+Cp(i+1);
Cp_f(j+17)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.85)+Cp(i+1);
Cp_f(j+18)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.9)+Cp(i+1);
Cp_f(j+19)=-((Cp(i+1)-Cp(i))/(2-1))*(2-1.95)+Cp(i+1);
j=j+20;
end
Cp_f;

%Power January
Power_january=0; %in Wattios
rho=1.225; % air density (kg/m3)
A=12868; %Swept area (m2) Model G128-4.5MW
Power_january(v_january<=3) =
0.5*rho*A*Cp_f(1).*v_january(v_january<=3).^3;
Power_january(v_january>3 & v_january<=3.05) =
0.5*rho*A*Cp_f(1).*v_january(v_january>3 & v_january<=3.05).^3;
Power_january(v_january>3.05 & v_january<=3.1) =
0.5*rho*A*Cp_f(2).*v_january(v_january>3.05 & v_january<=3.1).^3;
Power_january(v_january>3.1 & v_january<=3.15) =
0.5*rho*A*Cp_f(3).*v_january(v_january>3.1 & v_january<=3.15).^3;
Power_january(v_january>3.15 & v_january<=3.20) =
0.5*rho*A*Cp_f(4).*v_january(v_january>3.15 & v_january<=3.20).^3;
```

```
…

Power_january(v_january>26.75 & v_january<=26.8) =
0.5*rho*A*Cp_f(476).*v_january(v_january>26.75 & v_january<=26.8).^3;
Power_january(v_january>26.8 & v_january<=26.85) =
0.5*rho*A*Cp_f(477).*v_january(v_january>26.8 & v_january<=26.85).^3;
Power_january(v_january>26.85 & v_january<=26.9) =
0.5*rho*A*Cp_f(478).*v_january(v_january>26.85 & v_january<=26.9).^3;
Power_january(v_january>26.9 & v_january<=26.95) =
0.5*rho*A*Cp_f(479).*v_january(v_january>26.9 & v_january<=26.95).^3;
Power_january(v_january>26.95 & v_january<=27.0) = 0;

% Power with Gamesa limitation 4.5 MW
Power_jnr=Power_january;
Power_jnr (Power_january>=4500000)=4500000;

% Power of 20 Gamesa WT
Power_jnr_20=Power_jnr.*20;
```

4. Primary Frequency Control was calculated considering the variations of the frequency and implementing the droop equation to get the power due to those frequency fluctuations every 15 s. Here is shown for the month of January how the power changes, $Eu_{fr,t}$ defined before in the document is called in this code *P_jnr_20_if*. The nomenclature of the January's power generation from the WP is *P_jnr_20* with no primary frequency control implication.

```
for j=1:length(freq_january_15)
        m(j)=(50-freq_january_15(j));
         if (m(j) < -0.25)
            Power_jnr_20_if(k) = Power_jnr_20(j)*(-0.1);
            elseif (m(j)> -0.25 && m(j)< -0.02)
            Power_jnr_20_if(k) = Power_jnr_20(j)*(-0.05);
                elseif (m(j)>= -0.02 && m(j)<= 0.02)
                Power_jnr_20_if(k) = 0;
                    elseif (m(j)> 0.02 && m(j)< 0.25)
                     Power_jnr_20_if(k) = Power_jnr_20(j)*0.05;
                     else
                        Power_jnr_20_if(k) = Power_jnr_20(j)*0.1;
         end
             k=k+1;
             j=j+1;
end
```

5. Another restriction that will be used in the GAMS simulations is when the frequency is at minimum level (-0.5 Hz), defined as $Eu_{fr,Hz,lim}$ previously in the document.

```
Power_jnr_20_low=1;
for p=1:178560
    Power_jnr_20_low(r) = Power_jnr_20(p)*0.1;
    r=r+1;
end
```

6. Now, how to do the extra pay that the National Grid UK gives to the renewable generators if they need to cut off or to produce more for balancing the grid (mostly they

do it for cutting off). We do the REE day ahead prices depending if low or high-frequency episode. Previously called in this document as $\lambda_{ufr,t}$ for the GAMS simulation.

```
j=1;
k=1;
for j=1:length(Power_jnr_20_if)
        if (Power_jnr_20_if(j) < 0.000001)
           REF(k) = intra_january_15(j)*0.75;
           elseif (Power_jnr_20_if(j) > 0.000001)
           REF(k) = intra_january_15(j)*1.25;
                   else
                      REF=0;
        end
            k=k+1;
            j=j+1;
end
```