19th International Conference on Renewable Energies and Power Quality (ICREPQ'21)
Almería (Spain), 28th to 30th July 2021
Renewable Energy and Power Quality Journal (RE&PQJ)

Grid access of non-synchronous generation: Review of the Spanish regulation

L. Rouco, E. Lobato
Universidad Pontificia Comillas
Alberto Aguilera, 23, 28015 Madrid, Spain

Abstract. The development of wind and solar photovoltaic generation depends critically on the access to the grid. In contrast to synchronous generation, the access to the grid of converter based generation (also called non-synchronous generation) is affected by a number of technical constraints. The Spanish regulation of the grid access of non-synchronous generation has been recently reformulated. This contribution will review the new regulation. The past regulation will be also discussed.

Keywords. Grid access, Non-synchronous generation, Short Circuit Ratio.

1. Introduction

Decarbonization of economies to fulfill the Paris agreement goals requires the development of huge amounts of renewable power generation. Wind and solar photovoltaic power generation technologies have become technically mature and economically competitive technologies.

The Spanish National Program of Energy and Climate foresees that the wind installed capacity will become 50 GW in 2030 from the current 27 GW and that the solar photovoltaic installed capacity will become 39 GW in 2030 from the current 11 GW ([1], [2]).

Wind and solar photovoltaic generation are connected to the grid through power electronic converters. It results in formidable challenges for power system stability, control and protection. Due to such fact, it can be stated that ac power systems are facing the largest transformation since Edison, Tesla and Westinghouse.

The development of wind and solar photovoltaic generation depends critically on the access to the grid. In contrast to synchronous generation, the access to the grid of converter based generation (also called non-synchronous generation) is affected by a number of technical constraints.

The Spanish regulation of the grid access of non-synchronous generation has been recently reformulated. This paper reviews the new regulation ([3], [4]). The past regulation will be also discussed ([5], [6]). The past regulation was based exclusively on the Short Circuit Ratio criterion [7]. The new regulation is based on the Weigthed Short Circuit criterion [8] together with steady-state and dynamic security assessments.

The paper is organized as follows. Section 2 reviews the past regulation. Section 3 details the new regulation. Section 4 provides the conclusions of the paper.

2. Past regulation

The first Spanish regulation on the connection of renewable energy sources to the grid dates from 1985. It was mainly aimed at addressing the connection of minihydro and cogeneration plants. A general requirement was that the capacity of the line should be greater than 50% of the nominal power of the plant in case of plants smaller than 5000 kVA. It also addresses the connection of induction generators imposing that the voltage drop due to their starting should not be higher than 5%. In addition, the nominal power of wind generators should be smaller than 1/20 the short circuit capacity of the grid to avoid excessive voltage variations due to wind speed variation

$$\frac{P_n}{S_{sc}} \leq \frac{1}{20} \qquad (1)$$

where

S_{sc} is the short circuit capacity (apparent power) of the grid in MVA and
P_n is the nominal active power of the plant in MW

According to [7], the Short Circuit Ratio is defined

$$SCR = \frac{S_{sc}}{P_n} \qquad (2)$$

Hence, requirement (1) can be formulated as

$$SCR \geq 20 \qquad (3)$$

The physical meaning of the SCR is discussed. If the grid is represented at the point of connection by is Thévenin equivalent (see Fig. 1), the SCR is the inverse of the short circuit impedance Z_{sc}

$$SCR = \frac{1}{Z_{sc}(pu)} \quad (4)$$

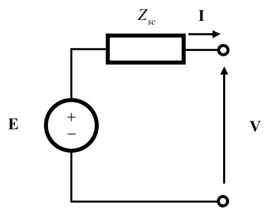


Fig. 1: Thévenin equivalent of the grid at the point of connection.

If the renewable power generator is connected to a low voltage grid (which grid impedance is resistive), the SCR is equal to the voltage variation when a generator that was suppling the nominal power with unity power factor trips (see Fig. 2).

$$\Delta V = V - E = 1 - 0.95 = 0.05pu = 5\%$$

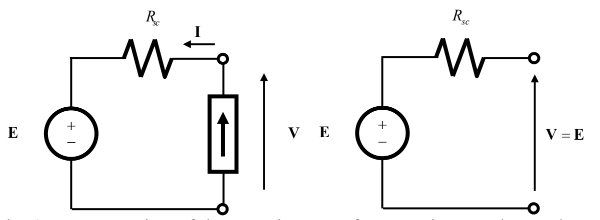


Fig. 2: Interpretation of the SCR in case of connection to a low voltage grid.

If the renewable power generator is connected to a high voltage grid (which grid impedance is inductive), the SCR is an upper bound equal to the voltage variation when a generator that was suppling the nominal power trips (see Fig. 3). Precisely if the power factor is 0.9 lagging, the voltage variation becomes 2.29%.

$$\begin{aligned} \mathbf{E} &= \mathbf{V} - jX_{sc}\mathbf{I} \\ &= 1.0 - j0.05 \cdot (1 - j0.4843) \\ &= 0.9771pu \end{aligned}$$

$$\Delta V = V - E = 0.0229 = 2.29\%$$

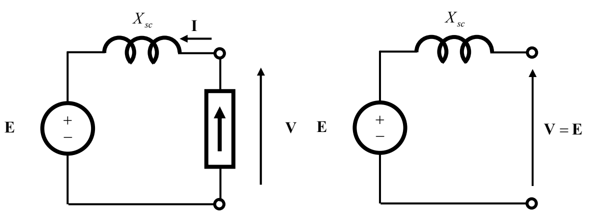
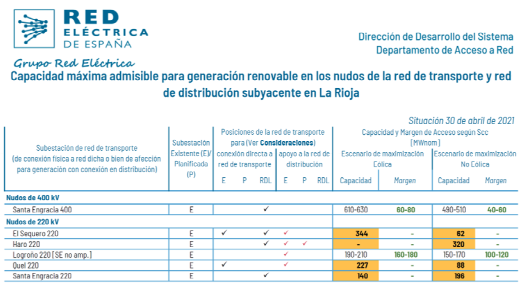


Fig. 3: Interpretation of the SCR in case of connection to a high voltage grid.

Royal Decree 413/2014 of 6 June extended to all non-manageable renewable energy resources the requirement of the Ministry Order of 1985. Non-manageable renewable energy resources include wind and solar photovoltaic. It assumes that solar thermal is manageable. It does not consider the possibility of hybrid plants that make manageable wind or solar photovoltaic plants with the aid of energy storage systems.

The Spanish TSO periodically published the grid access capability. Fig. 4 shows the grid access capability according to the past regulation as published by the Spanish TSO on 30 April 2021 in La Rioja region [9]. La Rioja region has one 400 kV and five 220 kV buses.



RED ELÉCTRICA DE ESPAÑA
Grupo Red Eléctrica

Dirección de Desarrollo del Sistema
Departamento de Acceso a Red

Capacidad máxima admisible para generación renovable en los nudos de la red de transporte y red de distribución subyacente en La Rioja

Situación 30 de abril de 2021

Subestación de red de transporte (de conexión física a red dicha o bien de afección para generación con conexión en distribución)	Subestación Existente (E)/ Planificada (P)	Posiciones de la red de transporte para (Ver Consideraciones): conexión directa a red de transporte			apoyo a la red de distribución			Capacidad y Margen de Acceso según Scc [MWnom]: Escenario de maximización Eólica		Escenario de maximización No Eólica	
		E	P	RDL	E	P	RDL	Capacidad	Margen	Capacidad	Margen
Nudos de 400 kV											
Santa Engracia 400	E			✓				610-630	60-80	490-510	40-60
Nudos de 220 kV											
El Sequero 220	E	✓		✓	✓			344	-	62	-
Haro 220	E			✓	✓	✓		-	-	320	-
Logroño 220 [SE no amp.]	E				✓			190-210	160-180	150-170	100-120
Quel 220	E	✓			✓			227	-	88	-
Santa Engracia 220	E			✓				140	-	196	-

Fig. 4: Grid access capability according to the past regulation as published by the Spanish TSO on 31 April 2021 in La Rioja region.

3. New regulation

All stakeholders agreed that new regulation was needed to allow the grid integration of the large amount of renewable energy resources foreseen in the natioFig. 5nal plan on energy and climate (PNIEC). Works started in fall 2019 reviewing the SCR criterion. It must be noted that the Spanish power system is the only system (to the author's knowledge) that uses the SCR criterion to determine the grid access capability. The motivation for keeping the SCR criterion has been on the impact of grid strength on the stability of the controls of wind generators based on double fed induction (DFIGs). Fig. 5 shows root locus of as the SCR changes for two design options of the bandwidth of PLL controller: 0.2 and 0.3 of the bandwidth of the current controllers. It confirms that a pair of complex poles may become unstable when the grid is very weak.

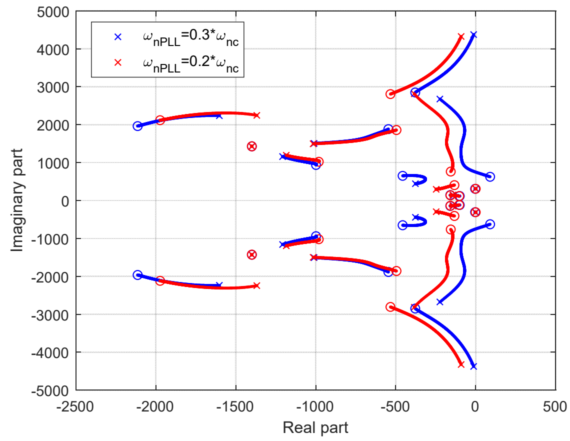


Fig. 5: Root locus of as the SCR changes for two design options of the bandwidth of PLL controller.

The new regulation comprises two pieces of legislation

- CNMC (National Comission for Markets and Competition) Circular 1/2021 of 20 January
- CNMC Resolution of 20 May 2021

CNMC Circular 1/2021 of 20 January establishes that grid access capacity of asynchronous generation (generation connected to the grid through power electronic converters) is determined by three criteria

- Short circuit capacity
- Static security
- Dynamic security

CNMC Resolution of 20 May 2021establishes detailed specifications for grid access capacity calculations to

- Transmission grid
- Distribution grids

A. Grid access to transmission grids

The grid access to the transmission grids is determined by short circuit capacity and static and dynamic security criteria. Transmission grid in mainland Spain is the grid at 400 and 220 kV. Transmission grid in the Spanish isolated systems is the grid at 220, 132 and 66 kV.

1) Short circuit capacity

The short circuit capacity criterion requires that Weighted Short Circuit Ratio (WSCR) of the power park modules within their area of influence should be greater than

- 10 when there are power park modules that do not fulfill EU Comission Regulation 2016/631 [11]
- 6 when all power park modules fulfill EU Comission Regulation 2016/631

The WSCR is defined as [8]

$$WSCR = \frac{\sum_i S_{sc,i} \cdot P_{n,i}}{\left(\sum_i P_{n,i}\right)^2}$$

The area of influence is determined using the Multi In-feed Influence Factor (MIFF) which is defined as ([12], [13])

$$MIIF_{ij} = \frac{\Delta V_i}{\Delta V_j}$$

The MIIFs can be calculated using either non-linear (power flow) of linear (short circuit) models of the power system as shown in Fig. 6.

The non-linear power system model is described by the linearized power flow equations in terms of the Jacobian matrix

$$\begin{bmatrix} \dfrac{\partial \mathbf{P}}{\partial \boldsymbol{\theta}} & \dfrac{\partial \mathbf{P}}{\partial \mathbf{V}} \\ \dfrac{\partial \mathbf{Q}}{\partial \boldsymbol{\theta}} & \dfrac{\partial \mathbf{Q}}{\partial \mathbf{V}} \end{bmatrix} \begin{bmatrix} \Delta \boldsymbol{\theta} \\ \Delta \mathbf{V} \end{bmatrix} = \mathbf{J} \begin{bmatrix} \Delta \boldsymbol{\theta} \\ \Delta \mathbf{V} \end{bmatrix} \begin{bmatrix} \Delta \mathbf{P} \\ \Delta \mathbf{Q} \end{bmatrix}$$

Hence, MIIFs can be calculated as

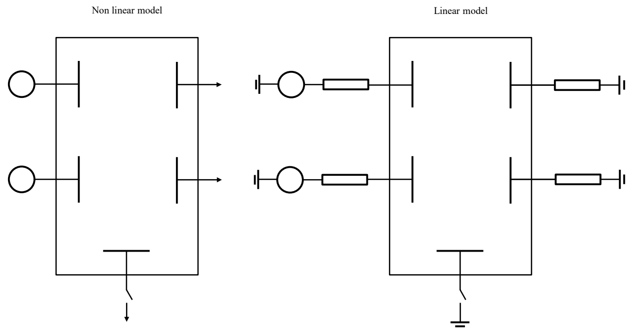


Fig. 6: Non-linear and linear power system models.

$$MIIF_{ij} = \left.\frac{\Delta V_j}{\Delta V_i}\right|_{\Delta Q_i = 1} = \frac{\mathbf{J}^{-1}_{\Delta Q_i, \Delta V_j}}{\mathbf{J}^{-1}_{\Delta Q_i, \Delta V_i}}$$

The linear power system model is described by the nodal equations in terms of admittance matrix

$$\mathbf{Y}_{bus} \mathbf{V} = \mathbf{I}$$
$$\mathbf{Z}_{bus} = \mathbf{Y}_{bus}^{-1}$$

Hence, MIIFs can be calculated as

$$MIIF_{ij} = \left.\frac{\Delta V_j}{\Delta V_i}\right|_{\Delta I_i = 1} = \frac{Z_{bus,ij}}{Z_{bus,ii}}$$

We believe as [12] that the use of a power system linear model is much more helpful to understand physically the areas of influence.

Power park modules belong to the same area of influence if $MIIF_{ij}$ is greater than 0.98. It is very interesting to note that the **MIIF** matrix is not symmetric. Let us consider a simple example to show it. Fig. 7 shows the single line diagram of the connection of a power park module to a 400 kV grid through a 400/132 kV transformer. The transformer nominal power and reactance are provided. The short circuit capacity of the 400 kV grid is also provided.

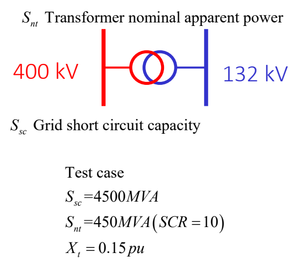


Fig. 7: Test case to illustrate MIIF.

Fig. 8 shows the equivalent circuit of the test case of Fig. 7.

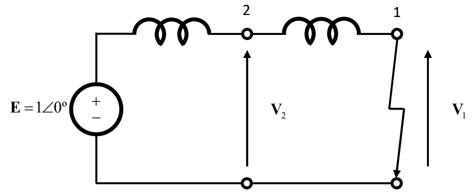


Fig. 8: Equivalent circuit of the test case used to illustrate MIIF.

The MIIFs are computed as follows

$$MIIF_{12} = \frac{\Delta V_2}{\Delta V_1} = \frac{\frac{X_t}{X_{sc}+X_t}-1}{-1} = \frac{\frac{0.15}{\frac{450}{4500}+0.15}-1}{-1} = 0.4$$

$$MIIF_{21} = \frac{\Delta V_1}{\Delta V_2} = \frac{0-1}{0-1} = 1$$

Hence the **MIIF** matrix becomes

$$\mathbf{MIIF} = \begin{bmatrix} 1.0 & 0.4 \\ 1.0 & 1.0 \end{bmatrix}$$

The **MIIF** must be transformed to a symmetric matrix as follows

$$\mathbf{MIIF}_{tranf} = \begin{bmatrix} 1.0 & 1.0 \\ 1.0 & 1.0 \end{bmatrix}$$

It means that buses number 1 and 2 are within the same area of influence. This simple example indicates that power park modules connected radially to a transmission grid bus will always belong to the area of influence of such transmission grid bus.

2) Steady-state security

Fulfilment of the steady-state security criterion requires that the grid is able to evacuate the renewable plant production for 90% of the time. In other words, there is absence of non-admissible overloads in N and N-X conditions as required in Operational Procedure 1.1 [14]. It means that congestion management measures could be applied during 10% the time. In addition, transmission grid development criteria imposed by Operational Procedure 13.1 are fulfilled [15].

The renewable plant ability of delivering its production 90% of the time is connected with requirements of article 13.5 of REGULATION (EU) 2019/94 [16] and the generation-duration curves of wind and solar PV sources (see Fig. 9).

The calculation procedure comprises the following steps

- Hourly simulation of the planning horizon year using a single bus generation model
- Selection of representative hours by clustering (it assigns a probability to each representative hour)
- Calculation of feasible productions using a generation-network model

CNMC Resolution of 20 May 2021 does not detail which is the assumed nominal power of each plant. We would assume that it is the nominal power calculated according to the short circuit capacity criterion.

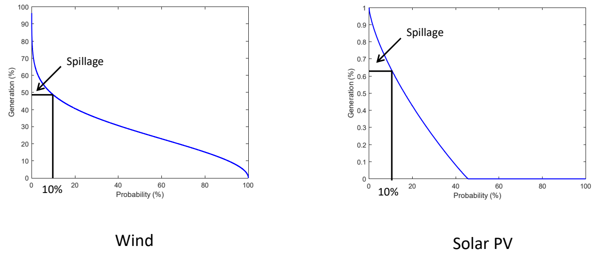


Fig. 9: Generation-duration curves of wind a solar PV and probability of spillage.

3) Dynamic security

Fulfilment of the dynamic-state security criterion requires that the critical clearing time of three phase fault at any bus should be greater 100 ms. In addition, the following conditions that must be fulfilled in case of 250 ms three phase faults

- Admissible post-fault operating point
- No area loss of synchronism
- No tripping of any France-Spain interconnection tie
- Generation tripping smaller than 3000 MW
- Damping of synchronous generator oscillations greater than 5%

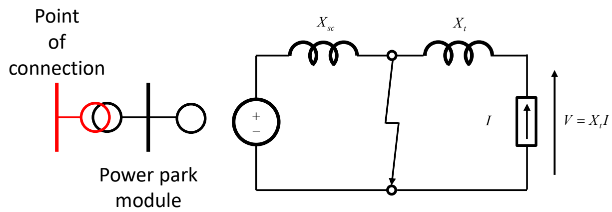


Fig. 10: Equivalent circuit of a power park module connected to the transmission grid in case of a three phase fault.

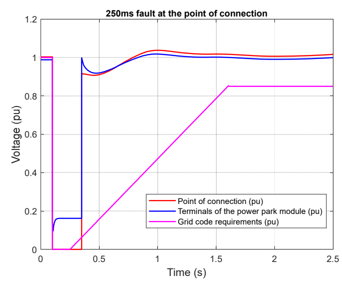
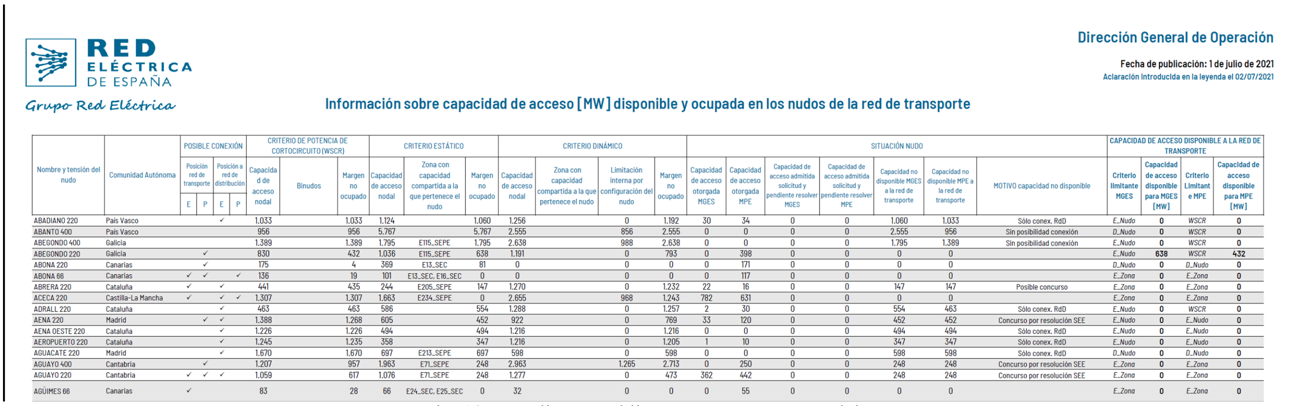


Fig. 11: Time domain simulation of a 250 ms three phase fault and the grid code requirement.



RED ELÉCTRICA DE ESPAÑA

Grupo Red Eléctrica

Dirección General de Operación

Fecha de publicación: 1 de julio de 2021

Aclaración introducida en la leyenda el 02/07/2021

Información sobre capacidad de acceso [MW] disponible y ocupada en los nudos de la red de transporte

Nombre y tensión del nudo	Comunidad Autónoma	POSIBLE CONEXIÓN				CRITERIO DE POTENCIA DE CORTOCIRCUITO (WSCR)			CRITERIO ESTÁTICO			CRITERIO DINÁMICO				SITUACIÓN NUDO							CAPACIDAD DE ACCESO DISPONIBLE A LA RED DE TRANSPORTE			
		Posición red de transporte		Posición a red de distribución		Capacidad de acceso nodal	Binudos	Margen no ocupado	Capacidad de acceso nodal	Zona con capacidad compartida a la que pertenece el nudo	Margen no ocupado	Capacidad de acceso nodal	Zona con capacidad compartida a la que pertenece el nudo	Limitación interna por configuración del nudo	Margen no ocupado	Capacidad de acceso otorgada MGES	Capacidad de acceso otorgada MPE	Capacidad de acceso admitida solicitud y pendiente resolver MGES	Capacidad de acceso admitida solicitud y pendiente resolver MPE	Capacidad no disponible MGES a la red de transporte	Capacidad no disponible MPE a la red de transporte	MOTIVO capacidad no disponible	Criterio limitante MGES	Capacidad de acceso disponible para MGES [MW]	Criterio Limitante MPE	Capacidad de acceso disponible para MPE [MW]
		E	P	E	P																					
ABADIANO 220	País Vasco			✓		1.033		1.033	1.124		1.060	1.256		0	1.192	30	34	0	0	1.060	1.033	Sólo conex. RdD	E_Nudo	0	WSCR	0
ABANTO 400	País Vasco					956		956	5.767		5.767	2.555		856	2.555	0	0	0	0	2.555	956	Sin posibilidad conexión	D_Nudo	0	WSCR	0
ABEGONDO 400	Galicia					1.389		1.389	1.795	E115_SEPE	1.795	2.638		988	2.638	0	0	0	0	1.795	1.389	Sin posibilidad conexión	E_Nudo	0	WSCR	0
ABEGONDO 220	Galicia		✓			830		432	1.036	E115_SEPE	638	1.191		0	793	0	398	0	0	0	0		E_Nudo	638	WSCR	432
ABONA 220	Canarias		✓			175		4	369	E13_SEC	81	0		0	0	0	171	0	0	0	0		D_Nudo	0	D_Nudo	0
ABONA 66	Canarias	✓	✓		✓	136		19	101	E13_SEC, E16_SEC	0	0		0	0	0	117	0	0	0	0		E_Zona	0	E_Zona	0
ABRERA 220	Cataluña	✓		✓		441		435	244	E205_SEPE	147	1.270		0	1.232	22	16	0	0	147	147	Posible concurso	E_Zona	0	E_Zona	0
ACECA 220	Castilla-La Mancha	✓		✓	✓	1.307		1.307	1.663	E234_SEPE	0	2.655		968	1.243	782	631	0	0	0	0		E_Zona	0	E_Zona	0
ADRALL 220	Cataluña			✓		463		463	586		554	1.288		0	1.257	2	30	0	0	554	463	Sólo conex. RdD	E_Nudo	0	WSCR	0
AENA 220	Madrid		✓	✓		1.388		1.268	605		452	922		0	769	33	120	0	0	452	452	Concurso por resolución SEE	E_Nudo	0	E_Nudo	0
AENA OESTE 220	Cataluña			✓		1.226		1.226	494		494	1.216		0	1.216	0	0	0	0	494	494	Sólo conex. RdD	E_Nudo	0	E_Nudo	0
AEROPUERTO 220	Cataluña			✓		1.245		1.235	358		347	1.216		0	1.205	1	10	0	0	347	347	Sólo conex. RdD	E_Nudo	0	E_Nudo	0
AGUACATE 220	Madrid			✓		1.670		1.670	697	E213_SEPE	697	598		0	598	0	0	0	0	598	598	Sólo conex. RdD	D_Nudo	0	D_Nudo	0
AGUAYO 400	Cantabria		✓			1.207		957	1.963	E71_SEPE	248	2.963		1.265	2.713	0	250	0	0	248	248	Concurso por resolución SEE	E_Zona	0	E_Zona	0
AGUAYO 220	Cantabria	✓	✓	✓		1.059		617	1.076	E71_SEPE	248	1.277		0	473	362	442	0	0	248	248	Concurso por resolución SEE	E_Zona	0	E_Zona	0
AGÜIMES 66	Canarias	✓				83		28	66	E24_SEC, E25_SEC	0	32		0	0	0	55	0	0	0	0		E_Zona	0	E_Zona	0

Fig. 12: Non-linear and linear power system models.

The Spanish implementation of the EU Commission Regulation 2016/631 [11] Order TED/749/2020, of 16 July [17]) imposes that power park modules do not disconnect from the grid in case of solid 150 ms three phase faults. However, Operational Procedure 13.1 [15]requires that above mentioned conditions are fulfilled in case of 250 ms three phase faults. The contradiction between both requirements is overcome thanks to the ability of power park modules to supply nominal reactive current in case of solid three phase faults. Fig. 10 shows the equivalent circuit that has to be considered to explain the voltage rise at the point of connection of the power park modules due to the supplied reactive current. Fig. 11 shows the results of the time domain simulation of a 250 ms three phase fault and the grid code requirement.

The Spanish TSO has published on 1 July 2021 the grid access capability according to the three aforementioned criteria [18]. Fig. 12 shows the grid access capability according to the new regulation as published by the Spanish TSO on 1 July 2021 for few sampled buses.

It is interesting to note that the disturbance that let to the incident occurred in Spanish mainland power system 24 July 2021 (the tripping of the interconnection ties with France) [19] was not considered within the catalogue of disturbances to be evaluated to ensure the dynamic security of the system.

B. Grid access to distribution grids

The minimum and the maximum nominal power of plant depend on distribution grid voltage as shown in Table I. In addition, the grid access to distribution grids is determined by short circuit capacity and static security criteria. Distribution grids in mainland Spain are the high voltage grids below 220 kV. Distribution grids in the Spanish isolated systems are the high voltage grids below 66 kV.

4) Short circuit capacity

In distribution grids, it is assumed that the area of influence contains only one node. Hence, the WSCR becomes the SCR

$$WSCR = \frac{\sum_i S_{sc,i} \cdot P_{n,i}}{\left(\sum_i P_{n,i}\right)^2} = \frac{S_{sc} \cdot P_n}{P_n^2} = \frac{S_{sc}}{P_n} = SCR$$

5) Steady-state security

Fulfilment of the steady-state security criterion requires that in both N and N-1 conditions there is not unserved power, there are no overloads in either transmission lines or transformers and the voltages are within the admissible ranges. In addition, the admissible voltage excursions in case of

- Single generator connection and tripping are
  >36 kV: ±2,5%
  <36 kV: ±3%

- Generators connected to a busbar tripping are
  >36 kV: ±4%
  <36 kV: ±5,5%

Table I: Minimum and maximum admissible power.

Grid nominal voltage (kV)	Minimum admissible power in a new position of a substation	Minimum admissible power by opening a line	Maximum admissible power in a new position of a substation
132	10	12	100
66	6	10	60
50-55	5	10	50
45	4	7	40
30	4	2	30
24-25	4	-	20
20	4	-	15
≤1 and ≥15	4	-	10
LV	-	-	0,1

4. Conclusions

Getting grid access is critical for the feasibility of the development of renewable power generation projects. Spanish regulation has recently changed (published in January and May 2021) The Spanish TSO has just published (1 July 2021) the grid access capability of each transmission grid node according to the new regulation.

Promoters of renewable energy projects need to understand the new regulation to be able to perform grid access capability calculations. The transparency of the calculation method requires that the input data and assumptions made should be public and that the tools and methods should be approved. The ultimate purpose of a transparent approach is that all participants are at identical conditions. A transparent approach should avoid any information asymmetry results in illegitimate competitive advantages of some participants with respect to others. Information confidentiality should not be used as excuse to avoid transparency. Solutions based on the use of default models exists.

References

[1] Ministerio para la Transición Ecológica y el Reto Demográfico, Plan Nacional Integrado de Energía y Clima, https://www.miteco.gob.es/images/es/pnieccompleto_tcm30-508410.pdf.

[2] Red Eléctrica de España, Informe del sistema eléctrico español 2020, https://www.ree.es/es/datos/publicaciones/informe-anual-sistema/informe-del-sistema-electrico-espanol-2020.

[3] Circular 1/2021, de 20 de enero, de la Comisión Nacional de los Mercados y la Competencia, por la que se establece la metodología y condiciones del acceso y de la conexión a las redes de transporte y distribución de las instalaciones de producción de energía eléctrica. BOE núm. 19, de 22 de enero de 2021, páginas 6111 a 6125.

[4] Resolución de 20 de mayo de 2021, de la Comisión Nacional de los Mercados y la Competencia, por la que se establecen las especificaciones de detalle para la determinación de la capacidad de acceso de generación a la red de transporte y a las redes de distribución. BOE núm. 131, de 2 de junio de 2021, páginas 67770 a 67786.

[5] Ministerio de Industria y Energía, Orden de 5 de septiembre de 1985 por la que se establecen normas administrativas y técnicas para funcionamiento y conexión a las redes eléctricas de centrales hidroeléctricas de hasta 5.000 kVA y centrales de autogeneración eléctrica. BOE núm. 219, de 12 de septiembre de 1985, páginas 28810 a 28814.

[6] Real Decreto 413/2914, de 6 de junio por el que se regula la actividad de producción de energía eléctrica a partir de fuentes de energía renovables, cogeneración y residuos. B.O.E. núm. 140, de 10 de junio de 2014, páginas 43876 a 43978.

[7] IEEE, IEEE Guide for Planning DC Links Terminating at AC Locations Having Low Short-Circuit Capacities, IEEE Std. 1204-1997, 1997.

[8] NERC, Integrating Inverter-Based Resources into Low Short Circuit Strength Systems. Reliability Guideline, December 2017, disponible en https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Item_4a._Integrating%20_Inverter-Based_Resources_into_Low_Short_Circuit_Strength_Systems_-_2017-11-08-FINAL.pdf.

[9] https://www.ree.es/sites/default/files/01_ACTIVIDADES/Documentos/AccesoRed/CAP_CON_NODAL_H2020_RIO_abr21.pdf

[10] R. Ávila-Martínez, L. Rouco, J. García Aguilar, J. Renedo, L. Sigrist, A. García-Cerrada, Impact of PLL control on small-signal stability of wind DFIGs connected to weak grids, 28 Seminario Anual de Automática, Electrónica industrial e Instrumentación, SAAEI'21, Ciudad Real 7-9 Julio 2021.

[11] Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, https://eur-lex.europa.eu/legal-content/ES/TXT/PDF/?uri=CELEX:32016R0631&from=EN.

[12] Ebrahim Rahimi, Voltage Interactions and Commutation Failure Phenomena in Multi-Infeed HVDC Systems, Department of Electrical and Computer Engineering University of Manitoba, 2011.

[13] Chengjun Xia, Xia Hua, Zhen Wang and Zhenlin Huang, Analytical Calculation for Multi-Infeed Interaction Factors Considering Control Modes of High Voltage Direct Current Links, Energies, 8 June 2018.

[14] Ministerio de Industria, Energía y Turismo, Resolución de 5 de abril de 2016, de la Secretaría de Estado de Energía, por la que se aprueba el procedimiento de operación del sistema eléctrico 1.1 «Criterios de funcionamiento y seguridad para la operación del sistema eléctrico», BOE, núm. 83, de 6 de abril de 2016, páginas 24013 a 24018.

[15] Ministerio de Industria, Energía y Turismo, Resolución de 22 de marzo de 2005, de la Secretaría General de la Energía, por la que se aprueba el Procedimiento de Operación 13.1. «Criterios de Desarrollo de la Red de Transporte», de carácter técnico e instrumental necesario para realizar la adecuada gestión técnica del Sistema Eléctrico. BOE núm. 85, de 9 de abril de 2005, páginas 12351 a 12358.

[16] Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0943&from=ES.

[17] Ministerio para la Transición Ecológica y el Reto Demográfico, Orden TED/749/2020, de 16 de julio, por la que se establecen los requisitos técnicos para la conexión a la red necesarios para la implementación de los códigos de red de conexión. BOE núm. 208, de 1 de agosto de 2020, páginas 62406 a 62458.

[18] https://d1n1o4zeyfu21r.cloudfront.net/Capacidad_de_acceso_a_RdT_ED_1jul21_1.pdf.

[19] REE, Repuesto el suministro eléctrico en las zonas afectadas de España tras un incidente en la red francesa que ha generado la desconexión temporal del sistema eléctrico peninsular del resto de Europa, Nota de prensa, 24 julio 2021, https://www.ree.es/es/sala-de-prensa/actualidad/nota-de-prensa/2021/07/comunicado-red-electrica-repuesto-el-suministro-electrico.