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

ICREPQ'21-Almería, Spain
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29 July 2021

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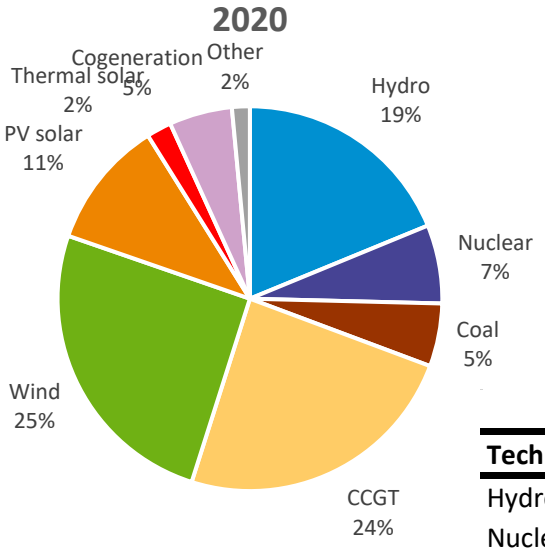
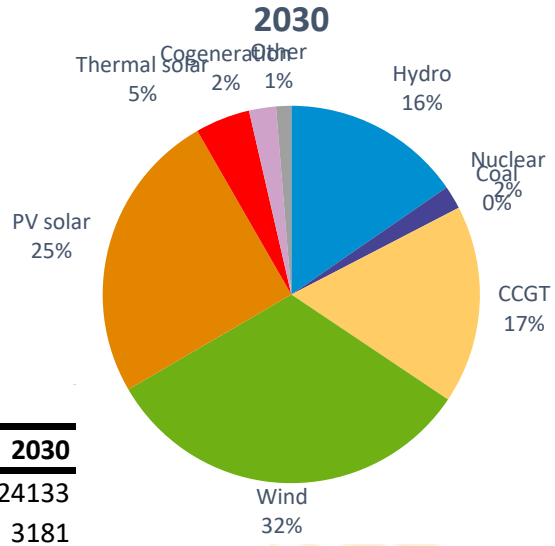
Introduction

- Decarbonization of the economy 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.

Introduction

- Installed capacity from 2020 to 2030 in Spain





Technology	2020	2030
Hydro	20429	24133
Nuclear	7117	3181
Coal	5733	0
CCGT	26250	26612
Wind	27485	50333
PV solar	11714	39181
Thermal solar	2304	7303
Cogeneration	5711	3670
Other	1676	1990
Total	108419	156403

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

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

Introduction

- 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.
- 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.

Past regulation

- Ministry of Industry and Energy Order of 5 September 1985
  - Mainly aimed at addressing the connection of minihydro and cogeneration plants
    - The capacity of the line should be bigger than 50% of the nominal power of the plant (in case of plants smaller than 5000 kVA)
  - It also addresses the connection of asynchronous generators
    - The voltage drop due to its starting should not be higher than 5%
    - 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

$$\frac{P_n}{S_{sc}} \leq \frac{1}{20}$$

S_{sc} Grid short circuit capacity (MVA)

P_n Plant nominal power (MW)

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 (B.O.E. No. 219, 12 septiembre 1985, páginas 28810 a 28814.

Past regulation

- Short Circuit Ratio (SCR)
  - Definition

$$SCR = \frac{S_{sc}}{P_n}$$

S_{sc} Grid short circuit capacity (MVA)

P_n Plant nominal power (MW)

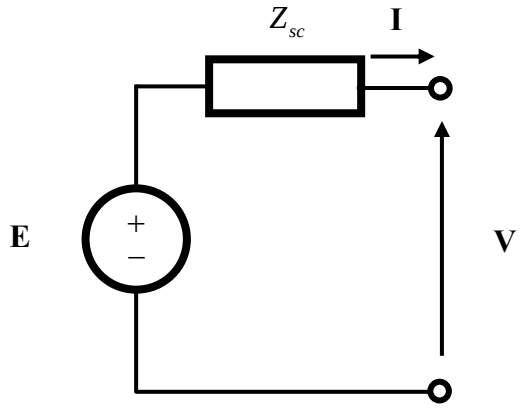
  - Requirement

$$SCR = \frac{S_{sc}}{P_n} \geq 20$$

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

Past regulation

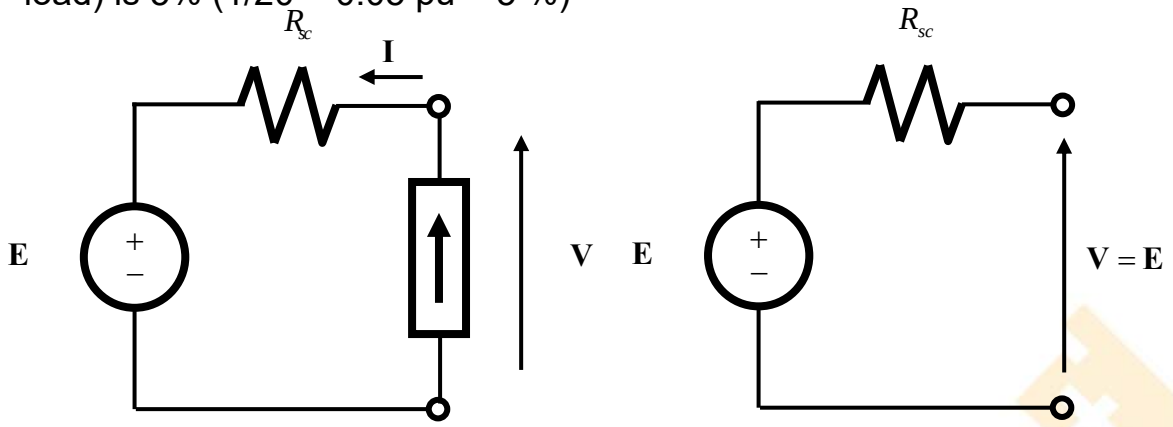
- Short Circuit Ratio (SCR)
  - Physical meaning



$$SCR = \frac{S_{sc}\left(MVA\right)}{P_n\left(MW\right)} = \frac{1}{Z_{sc}\left(pu\right)}$$

Past regulation

- Short Circuit Ratio (SCR)
  - Physical meaning
    - Low voltage grid
      - The voltage variation at the point of connection when the plant trips (if supplying its full load) is 5% (1/20 = 0.05 pu = 5 %)

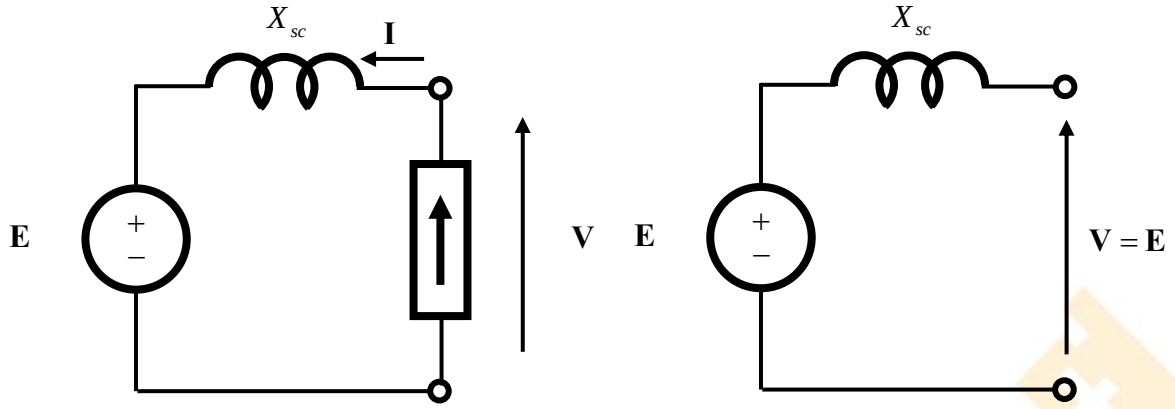


Full load with
unity power factor

$$SCR = \frac{1}{R_{sc}} \qquad \Delta V = V - E = 1 - 0.95 = 0.05\,pu = 5\%$$

Past regulation

- Short Circuit Ratio (SCR)
  - Physical meaning
    - High voltage grid
      - The voltage variation at the point of connection when the plant trips (if supplying its full load) is smaller than 5%



Full load with
0.9 lag power factor

$$\mathbf{E} = \mathbf{V} - jX_{sc}\mathbf{I}$$

$$= 1.0 - j0.05 \cdot (1 - j0.4843)$$

$$= 0.9771 pu$$

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

Past regulation

- Royal Decree 413/2014 of 6 June
  - Nominal power of non-manageable generation should be smaller than 1/20 the short circuit capacity of the grid
    - Non-manageable includes
      - Wind
      - Solar photovoltaic
    - I assumes that solar thermal is manageable
    - It does not considers the posibility of hybrid plants that make manageble wind or solar photovoltaic plants with the aid of energy storage systems

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

Past regulation

- The Spanish TSO periodically published the grid access capability
  - Last publication according to the past regulation: 30 April 2021
    - La Rioja region

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**	-

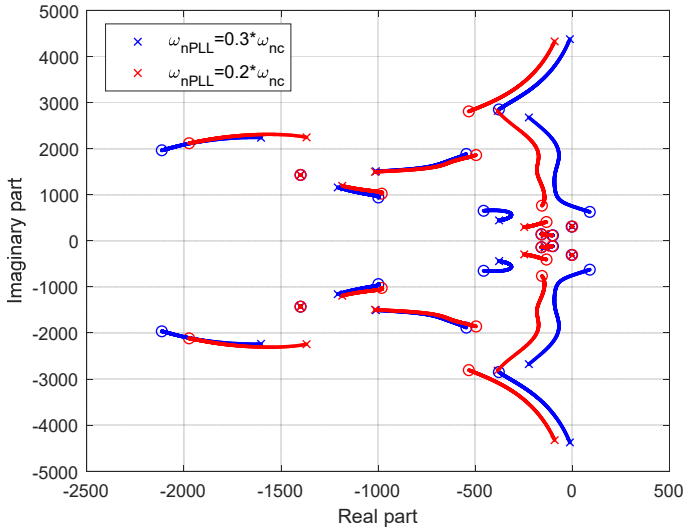
https://www.ree.es/sites/default/files/01_ACTIVIDADES/Documentos/AccesoRed/CAP_CON_NODAL_H2020_RIO_abr21.pdf

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 national 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

New regulation

- New motivation of incorporating the SCR requirement
  - Impact of the SCR on the controls stability of a DFIG



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.

New regulation

- CNMC (National Comission for Markets and Competition) Circular 1/2021 of 20 January
  - Asynchronous generation (generation connected to the grid through power electronic converters)
    - Short circuit capacity
    - Static security
    - Dynamic security
- CNMC (National Commission for Markets and Competition) Resolution of 20 May 2021
  - Detailed specifications
    - Transmission grid
    - Distribution grids

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.
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.

New regulation: Transmission grid

- Short circuit capacity
  - Weighted Short Circuit Ratio (WSCR) of the power park modules within their area of influence
    - >10 when there are power park modules that do not fulfill EU Comission Regulation 2016/631
    - >6 when all power park modules fulfill EU Comission Regulation 2016/631

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

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
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

New regulation: Transmission grid

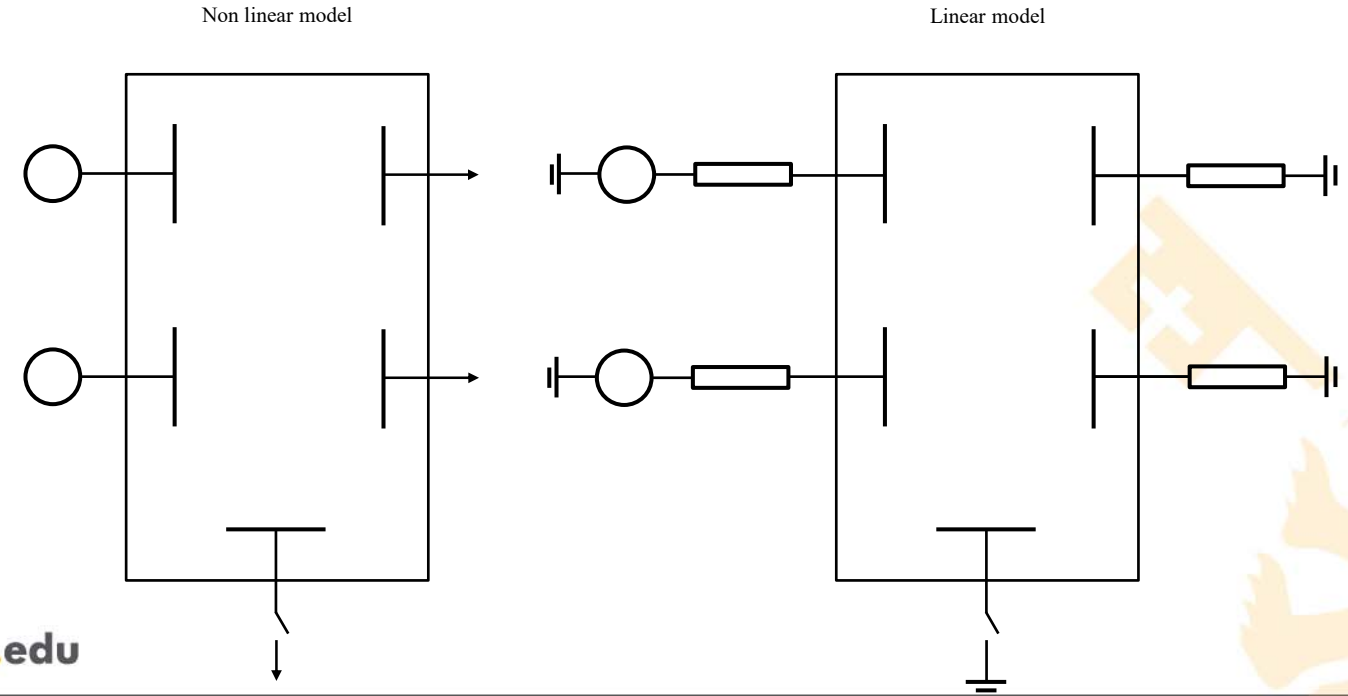
- Short circuit capacity
  - Weighted Short Circuit Ratio (WSCR) of the power park modules within their area of influence
    - The area of influence is determined by the Multi-Infeed Influence Factor (MIIF)

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

$$MIIF_{ij} \geq 0.98$$

New regulation: Transmission grid

- Short circuit capacity
  - Weighted Short Circuit Ratio (WSCR) of the power park modules within their area of influence
    - Multi-Infeed Influence Factor (MIIF) computation approach
      - Short circuit (linear)
      - Power Flow (non linear)



New regulation: Transmission grid

- Short circuit capacity
  - Weighted Short Circuit Ratio (WSCR) of the power park modules within their area of influence
    - Multi-Infeed Influence Factor (MIIF) computation approach
      - Short circuit (linear)
      - Power Flow (non linear)

$$\mathbf{Y}_{bus}\mathbf{V} = \mathbf{I}$$

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

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

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

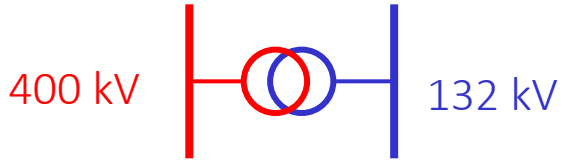
$$MIIF_{ij} = \left.\frac{\Delta V_j}{\Delta V_i}\right|_{\Delta Q_i = 1} = \frac{\mathbf{J}^{-1}_{\Delta Q_i, \Delta V_j}}{\mathbf{J}^{-1}_{\Delta Q_i, \Delta V_i}}$$

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

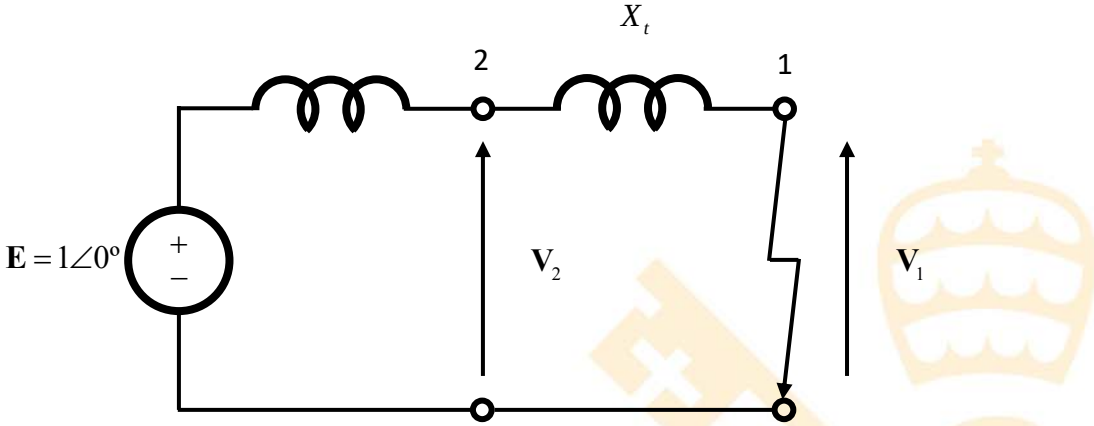
New regulation: Transmission grid

- Short circuit capacity
  - Weighted Short Circuit Ratio (WSCR) of the power park modules within their area of influence
    - Multi-Infeed Influence Factor (MIIF) computation approach
      - MIIFs are non-symmetrical

S_{nt} Transformer nominal apparent power



S_{sc} Grid short circuit capacity



Test case

S_{sc}=4500MVA

S_{nt}=450$MVA(SCR=10)$

$X_t = 0.15\,pu$

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

Fault at the node 2

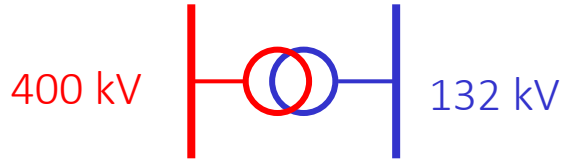
$$MIIF_{21} = \frac{\Delta V_1}{\Delta V_2} = \frac{0-1}{0-1} = 1$$

Fault at the node 1

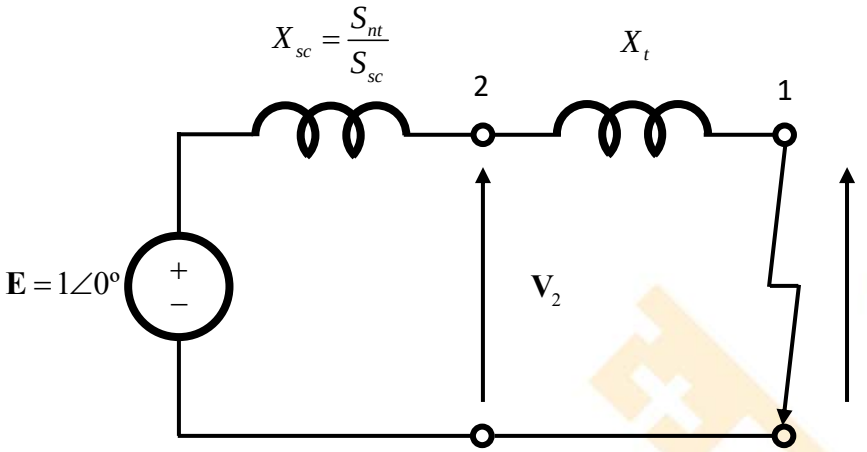
New regulation: Transmission grid

- Short circuit capacity
  - Weighted Short Circuit Ratio (WSCR) of the power park modules within their area of influence
    - Multi-Infeed Influence Factor (MIIF) computation approach
      - MIIFs are non-symmetrical

S_{nt} Transformer nominal apparent power



S_{sc} Grid short circuit capacity



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

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

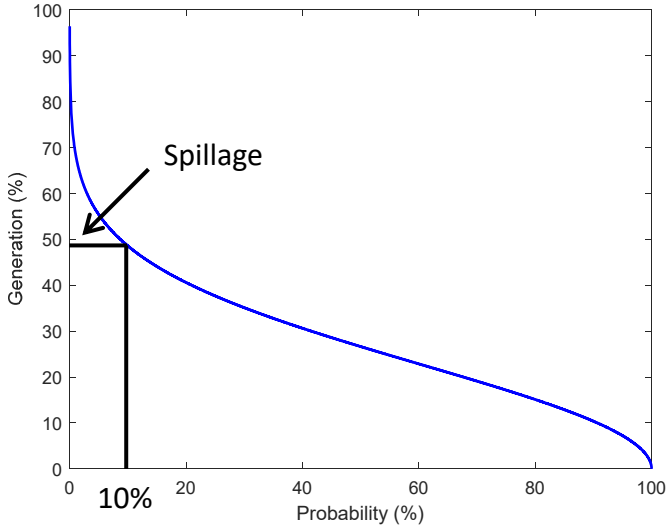
New regulation: Transmission grid

- Static security (power flow)
  - The grid is able to evacuate the renewable plant production for 90% of the time
    - Absence of non admisible overloads in N and N-X conditions as required in Operational Procedure 1.1
    - Congestion maganement measures could be applied during 10% the time
  - In addition, transmission grid development criteria imposed by Operational Procedure 13.1 are fulfilled
  - Calculation procedure
    - 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
      - It is not detailed which is the assumed nominal power of each plant (the nominal power calculated according to the short circuit capacity?)

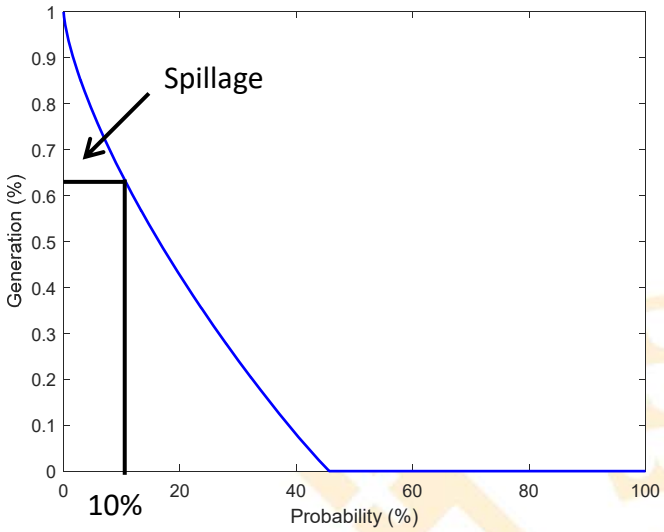
Ministerio de Industria, Energía y Turismo, Resolución de 5 de abril de 2016, de la Secretaría de Estado de Energía, por la que se aprueba el procedimiento de operación del sistema eléctrico 1.1 «Criterios de funcionamiento y seguridad para la operación del sistema eléctrico», BOE, núm. 83, de 6 de abril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

New regulation: Transmission grid

- Static security (power flow)
  - Generation-duration curves of wind and solar photovoltaic



Wind



Solar PV

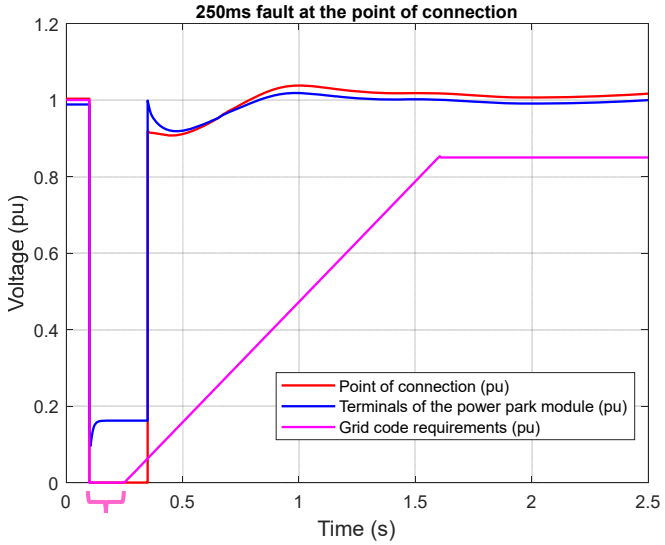
REGULATION (EU) 2019/943 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on the internal market for electricity, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0943&from=ES

New regulation: Transmission grid

- Dynamic security (transient stability)
  - The critical clearing time of three phase fault at any bus should be greater 100 ms
  - 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%

New regulation: Transmission grid

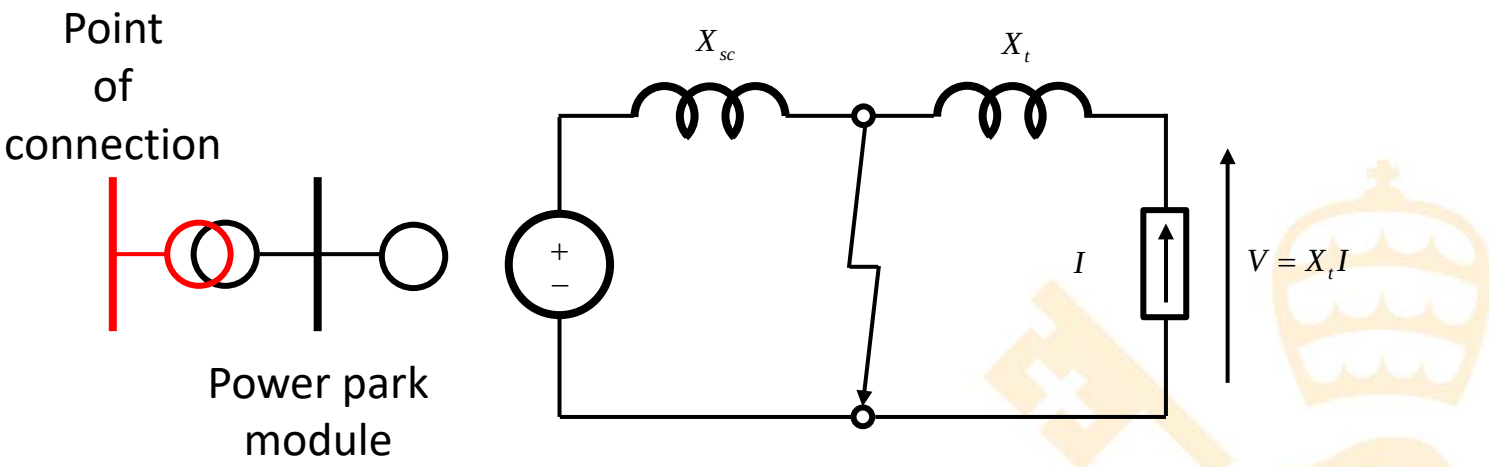
- Dynamic security (transient stability)
  - The Spanish implementation of the EU Comission Regulation 2016/631 (Order TED/749/2020, of 16 July) and 250 ms three phase fault requirement (Operational Procedure 13.1)



Grid code requirement: 150 ms fault

New regulation: Transmission grid

- Dynamic security (transient stability)
  - The Spanish implementation of the EU Commission Regulation 2016/631 (Order TED/749/2020, of 16 July) and 250 ms three phase fault requirement (Operational Procedure 13.1)



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.

New regulation: Transmission grid

- The Spanish TSO has recently (1 July 2021) published the grid access capability of each transmission grid node according to the new regulation

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

https://d1n1o4zeyfu21r.cloudfront.net/Capacidad_de_acceso_a_RdT_ED_1jul21_1.pdf

New regulation: Distribution grids

- Minimum and maximum admissible power

Grid nominal voltage (kV)	Minimum admisible power in a new position of a substatation	Minimum admisible power by opening a line	Maximum admisible 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

New regulation: Distribution grids

- Short circuit capacity
  - It is assumed that the area of influence contains only one node
    - The WSCR becomes the SCR

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

New regulation: Distribution grids

- Static security
  - In both N and N-1 conditions
    - There is not unserved power
    - There are no overloads in either transmission lines or transformers
    - The voltages are within the admissible ranges
  - Admissible voltage excursions in case of
    - Single generator connection and tripping
      - >36 kV: ±2,5%
      - <36 kV: ±3%
    - Generators connected to a busbar tripping
      - >36 kV: ±4%
      - <36 kV: ±5,5%

Conclusions

- Getting grid access is critical for the feasibility of renewable energy 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

Conclusions

- The transparency of the calculation method requires
  - The input data and assumptions made should be public
  - 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 illegitimite competitive adavantages 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