CLEAN ENERGY FOR EU ISLANDS

The Benefits of New 66kV Overhead Line in La Palma

Identifying and Analysing Technical Values of Investments

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The Clean Energy for EU Islands Secretariat

Who we are?

The launch of the Clean Energy for EU Islands Initiative in May 2017 underlines the European Union's intent to accelerate the clean energy transition on Europe's more than 1,400 inhabited islands. The initiative aims to reduce the dependency of European islands on energy imports by making better use of their own renewable energy sources and embracing modern and innovative energy systems. As a support to the launch of the initiative, the Clean Energy for EU Islands Secretariat was set up to act as a platform of exchange for island stakeholders and to provide dedicated capacity building and technical advisory services.

The Clean Energy for EU Islands Secretariat supports islands in their clean energy transition in the following ways:

- It provides technical and methodological support to islands to develop clean energy strategies and individual clean energy projects.
- It co-organises workshops and webinars to build capacity in island communities on financing, renewable technologies, community engagement, etc. to empower them in their transition process.
- It creates a network at a European level in which islands can share their stories, learn from each other, and build a European island movement.

The Clean Energy for EU Islands Secretariat provides a link between the clean energy transition stories of EU islands and the wider European community, in particular the European Commission.

1. Introduction

Because of isolation and territorial fragmentation, isolated power and energy systems are characterized for having a great requirement on fossil sources. The island of La Palma is located on the northwest of the Canary Islands, and its electric system is very small. Increasing the share of renewable energies and the decrease of fossil energies usage are planned by local authorities in the context of Sustainability policies. Nevertheless, intermittence, hard to predict, uncertain, and non-dispatchable renewable energies in few locations may hinder the operation of the system.

In order to achieve the main goal of the Canary Islands energy policy on sustainability, the penetration of renewables should be increased, in parallel with reducing the use of fossil fuels, which would also reduce emissions. The interconnection among different island systems would be a potential solution. However, the great depth of the seabed in the archipelago makes that two of the islands (La Palma and El Hierro) remain completely isolated. In these cases, energy storage and improving the operation and control practices are almost the only solution in order to increase the share of renewables and, at the same time, guaranteeing the electric supply.

La Palma is an island belonging to the Canary Islands archipelago and declared a Biosphere Reserve by UNESCO since 2002. Currently, thermal plants provide the vast majority energy, while only a small proportion is provided by wind and solar power parks. The objective for next years is to reduce consumption of fossil fuel and increase the use of renewable resources. For this purpose, it is expected to increase the installed capacity of wind and solar farms and to build a storage in the island. One of the main objectives to be achieved in future is that at certain times, the energy is produced exclusively from renewable sources, thus overriding the thermal generation.

Objectives

As part of a Call for Proposals launched in 2019 for project support to islands, the Clean Energy for EU Islands Secretariat is providing Technical Advisory services to the La Palma island in Spain. This technical note covers the technical benefits, disadvantages, and considerations of commissioning the planned 66kV overhead line and recommendations on further studies to further investigate this project. New planned OHL can bring primarily lower interruption cost to the island alongside with improving the grid security and reliability, higher share of renewables and can help reduce the potential for power outages.

All transmission projects have characteristics that relate to reliability, economics, and operations. However, reliant on on the type of project, the processes of economic evaluation and cost recovery of projects diverges. Transmission projects are generally grouped into four categories:

- Upgrades as requested,
- Interconnection of generations,
- Reliability (Base Plan Upgrades), and
- Economic (Complementary Upgrades).

Demanded upgrades are projects that meet specific request or requirements of a customer and are usually paid by the customer. Generation interconnection usually paid by the generator, aims to connect a new power plant. If a new significant power plant is being added to the system there may be need for system upgrades as well.

Reliability projects such as the one in La Palma island are transmission improvement that may be required to satisfy the existing or new reliability criteria. Without such a transmission, there is potential for reliability related problems and failure to meet the established reliability criteria.

The first three types of projects go usually forward with little or no opposition —upgrades, power plant interconnection, and reliability projects because of having clear drivers or mandates. However, economic projects (including projects that address specific policy objectives such as for higher renewables penetration and removing bottlenecks) often may get obstructed due to different perspectives on need, benefits, and cost responsibility.

Costs and benefit analysis of a network expansion is conveyed through Techno-Economical Calculations using the Net Present Value. Analyses of investment costs, cost of losses, interruption costs and the project schedules' economic influence. In the available calculations for the expansion planning in La Palma, only the interruption costs and investment costs have been considered as economic measures. However, different non-monetizable and monetizable economic and technical aspects could be investigated in the transmission planning, such as, maximum power transfer limits, system losses, N-1 contingency, fault currents, transient stability, and low frequency ossifications. This study aims to cover the technical impact analysis of the new line in static and dynamic points of view either through simulations or analytics (in case of unavailability of the required information for simulation).

Guide to the reader

3E is the author of this document. 3E is an independent consultancy and software service company headquartered in Brussels, Belgium, that for 20 years has delivered solutions for performance optimisation of renewable energy and energy efficiency projects in over 40 countries and is a trusted party for the major lenders and equity providers in the global renewable energy market. 3E is also in charge of the technical work package of the Clean Energy for EU Islands Secretariat.

The inherent tasks for the conclusion of the present study are separated under the following chapters:

- **Section 2** presents La Palma power grid's main characteristics as per the received information from Client.
- **Section 3** covers the description of the new planned 66kV line and existing reliability-oriented cost-benefit analysis.
- **Section 4** addresses the power-flow simulations assessing voltages, loadings, and loss impacts of the planned line on the La Palma grid.
- **Section 5** covers the contingency analysis.
- **Section 6** covers the short circuit analysis.
- **Section 7** covers the dynamic stability of the grid including steady state, rotor angle, small signal, and voltage stabilities. As per the unavailability of dynamic data, dynamic stability is enclosed analytically.
- **Section 8** covers the systematic impact of the new line on the protection coordination of the island.
- **Section 9** presents the recommendations for further studies.
- **Section 10** presents the conclusion of the studies for technical benefits and disadvantages of the planned line.

2. La Palma Island Power Grid

As per "ANUARIO ENERGÉTICO DE CANARIAS 2017", the total gross electricity installed in the Canary Islands as of December 31, 2017 was 3,119.7 MW, increasing by 55.7 MW compared to the previous year, an increase of 1.8%. It is observed that this increase was mainly due to the power installed in Gran Canaria and Tenerife, and to a lesser extent, in Fuerteventura and Lanzarote. On the other hand, in La Palma (117,8 MW in 2017 and 117,7 MW in 2016), La Gomera and El Hierro the installed power has not changed compared to the previous year.

In the Canary Islands, the exchanged energy in 2017 was 8,957.04 GWh, which was an increase from the previous year's value of 2.1%. Of this total, Gran Canaria and Tenerife accounted for 78.3% of energy. By islands, with the exception of El Hierro, whose exchanged energy decreased by 1.7%; in the rest the variations have been positive, moving in ascents from 0.4% of Tenerife, to the maximum of 6.9% in La Palma (260,75 GWh in 2017 and 243,84 GWh in 2016).

According to peak demand information grouped by hour[1], peak demand in La Palma is 43.84 MW, in 2017. We also checked https://demanda.ree.es/visiona/canarias/la_palma/total/2019-08-20 going through summer days of 2019 and the peak is in the same day at 43 MW. We think it's safe to assume that peak demand will not increase that much and that it's currently around 43 MW. Far from the projections of the first document with the planning 2015-2020, with 61 MW and 54 MW scenarios. In below[2], total demand is predicted as 61MW in maximum load level and 54MW in medium load levels of 2020. Total demand over the last couple of years hasn't changed that much, so the above estimations are probably quite high.

Año	Punta de demanda media horaria en b.c. (MW). Escenario Superior						
	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro
2012	579	568	140	110	45,5	12,0	7,5
2013	542	548	138	108	42	11,3	8,0
2015 (P)	595	589	146	116	49,8	12,5	7,9
2020 (P)	688	707	172	143	61	14,8	9,9
Año	**Punta de demanda media horaria en b.c. (MW). Escenario Central**						
	Gran Canaria	**Tenerife**	**Lanzarote**	**Fuerteventura**	**La Palma**	**La Gomera**	**El Hierro**
2012	579	568	140	110	45,5	12,0	7,5
2013	542	548	138	108	42	11,3	8,0
2015 (P)	572	567	140	112	47,9	12,0	7,6
2020 (P)	612	629	153	128	54	13,2	8,8

- Population of La Palma island isn't growing considerably from 2015 to 2025 and accordingly, almost the same behaviour would be predictable for the electricity demand of the island.
- Based on the renewable target of 2025, current peak load of La Palma could be outstandingly supplied by renewable production, if proper grid infrastructure and efficient operational practices are considered for reliable and secure operation of the grid.

Large-scale energy storage systems are planned in islands, in addition to the facilities already authorized, being processed or planned at the state level:

[1] We couldn't get with a lower resolution.
[2] https://energia.gob.es/planificacion/Planificacionelectricidadygas/desarrollo2015-2020/Documents/Planificaci%C3%B3n%202015_2020%20%202016_11_28%20VPublicaci%C3%B3n.pdf

- hydroelectric pumping of El Hierro (11.5 MW) and Gran Canaria (200 MW) –
- other additional hydro pumps on the islands of Tenerife (90 MW) and La Palma (30 MW).

Promote the implementation of energy storage systems, by installing three hydro-pumping plants in Gran Canaria, Tenerife and La Palma, reaching, together with the El Hierro Hydroelectric Power Plant, a power of 332 MW on the 2025 horizon. The renewable sources including four wind farms (W) distributed throughout the island with an installed capacity of 9 MW and two solar photovoltaic (Pv) plants with an installed capacity of 4.9 MW are shown in Figure 1.

In the last years, several expansion plans have been developed in order to increase the penetration of renewable energy throughout the archipelago. According to the penetration rate of these energies in recent years and taking into account the development plans of the energy system, it is considered that the most likely action would be to install a wind farm of about 20 MW. In this scenario, it would be necessary to have sufficient power regulation capacity in a pumped storage hydroelectric plant (PSHP) for integration of the other renewable energy sources. Pumped storage system structure is presented in Figure 2.

Figure 1 Geographical location of La Palma island in the Canary Archipelago, and its renewable power plants

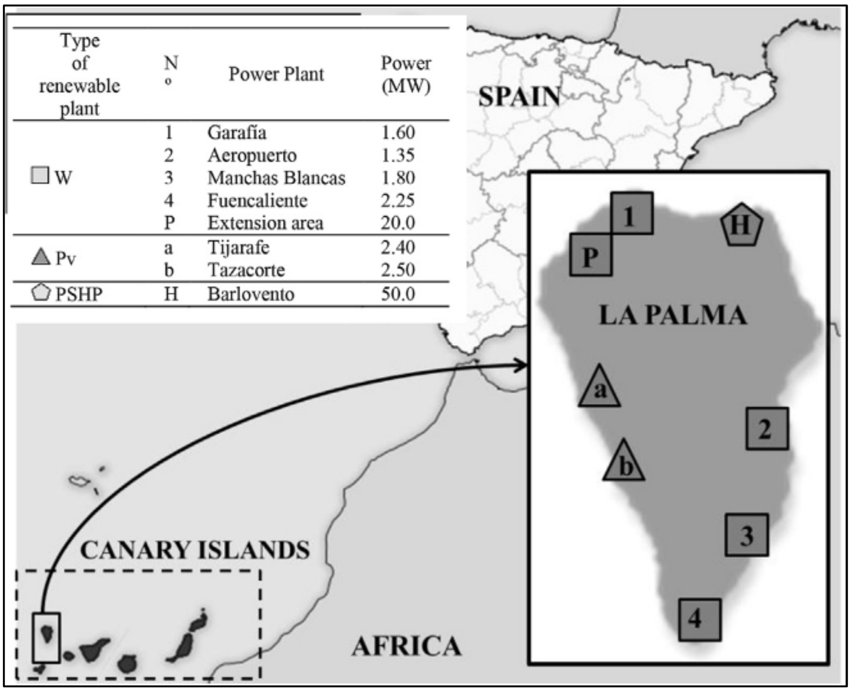
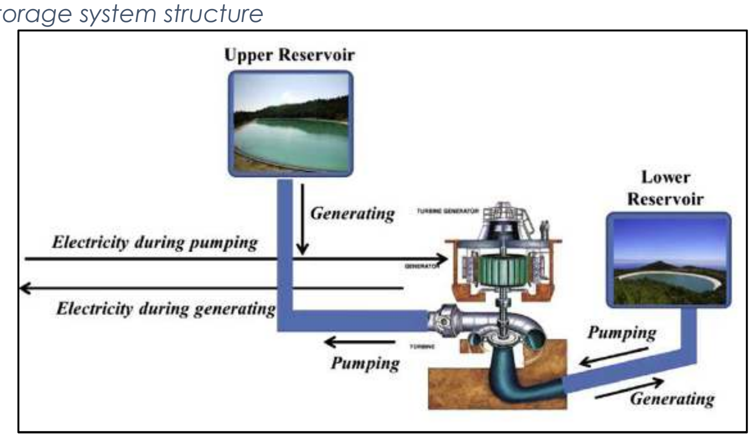


Figure 2 Pumped storage system structure

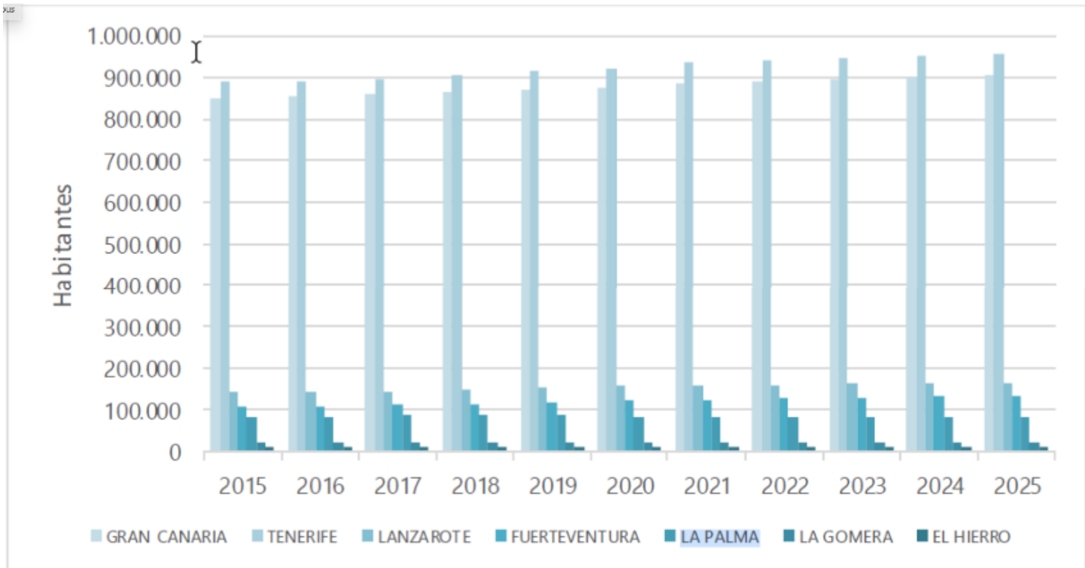


Gathered information on the operation and planning of Canary Islands mainly in case of La Palma are presented in the following figures found from the information and reports received form the Client.

Figure 3 Objectives of installed renewable power in the Canary Islands, by islands

Tecnología	Capacidad instalada de origen renovable para la generación eléctrica con vertido a red, por islas (MW)													
	Gran Canaria		Lanzarote		Fuerteventura		Tenerife		La Palma		La Gomera		El Hierro	
	2015	2025	2015	2025	2015	2025	2015	2025	2015	2025	2015	2025	2015	2025
Eólica	86,72	408,50	8,78	81,00	13,09	87,00	36,68	412,00	6,97	21,00	0,36	4,00	11,50	11,50
Eólica off shore	0,00	180,00	0,00	10,00	0,00	10,00	0,00	100,00	0,00	10,00	0,00	0,00	0,00	0,00
Fotovoltaica	39,59	65,62	7,77	13,12	13,05	21,82	114,93	191,60	4,60	7,72	0,04	0,06	0,03	0,08
Biomasa eléct.	0,00	10,00	2,10	2,50	0,00	1,50	1,60	10,00	0,00	0,50	0,00	0,50	0,00	0,50
Total isla	**126,31**	**664,12**	**18,65**	**106,62**	**26,14**	**120,32**	**153,21**	**713,6**	**11,57**	**39,22**	**0,4**	**4,56**	**11,53**	**12,08**

Figure 4 Expected evolution of the population in the Canary Islands, by islands



The following tables present the installed power on each island and for the total of the Archipelago at the end of 2017 according to the type of energy source used. In these terms of installed power, renewable energy accounted for 13.6% of the total of the Canary Islands by adding 423.4 MW distributed mainly between wind power with 212.8 MW (50.3%) and photovoltaic with 182 MW (43.0 %).

La Palma island is showing constant installed power for the last ten years entailing 105.3MW (82.8MW diesel and 22.5MW gas) thermal and 12.4MW (7MW wind, 4.6MW PV, and 0.8MW mini hydro) renewable generations.

Figure 5 Evolution of electric power installed in the Canary Islands on 31 December 2017, by islands per MW

Tabla 3.1.1. Evolución anual de la potencia eléctrica en b.a. instalada en Canarias a 31 de diciembre, desglosada por islas

Año	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro	Canarias	Δ Canarias
1990	505,1	396,1	87,5	54,0	44,5	7,5	3,6	**1.098,3**	-
1995	633,3	644,3	108,4	91,5	53,3	11,4	7,3	**1.549,5**	-
1996	733,7	644,3	108,4	91,5	53,3	13,9	7,3	**1.652,4**	6,6%
1997	719,8	649,6	108,4	91,5	53,3	12,6	8,6	**1.643,8**	-0,5%
1998	742,3	655,2	144,9	91,5	54,8	12,6	8,6	**1.709,9**	4,0%
1999	745,0	667,4	145,9	91,5	54,8	14,1	8,6	**1.727,3**	1,0%
2000	767,0	667,2	145,9	129,0	51,6	15,9	10,0	**1.786,6**	3,4%
2001	754,3	673,0	144,9	129,0	64,2	15,9	9,3	**1.790,6**	0,2%
2002	755,5	673,0	180,9	129,0	64,2	16,2	10,3	**1.829,1**	2,2%
2003	905,3	876,0	201,3	184,8	88,9	19,7	9,0	**2.285,0**	24,9%
2004	980,3	876,0	201,3	184,8	89,0	19,7	9,1	**2.360,2**	3,3%
2005	981,0	970,5	200,9	219,7	89,3	23,1	13,3	**2.497,8**	5,8%
2006	981,3	1.024,6	231,4	210,5	89,3	23,1	13,3	**2.573,5**	3,0%
2007	1.144,5	1.043,7	234,7	213,8	114,4	23,3	13,1	**2.787,5**	8,3%
2008	1.169,5	1.091,9	236,6	215,7	91,3	23,3	12,9	**2.841,0**	1,9%
2009	1.241,5	1.086,3	226,2	217,6	114,3	23,2	13,1	**2.922,4**	2,9%
2010	1.247,0	1.256,1	227,2	206,0	116,0	23,2	13,1	**3.088,7**	5,7%
2011	1.251,7	1.333,0	229,1	210,8	116,4	23,2	13,1	**3.177,4**	2,9%
2012	1.178,3	1.268,8	230,3	212,8	117,6	23,2	13,1	**3.044,2**	-4,2%
2013	1.150,3	1.270,6	251,0	213,0	117,7	23,2	15,1	**3.040,9**	-0,1%
2014	1.150,7	1.270,6	251,0	213,1	117,7	23,2	35,9	**3.062,1**	0,7%
2015	1.150,4	1.266,0	250,9	213,2	117,7	23,0	37,8	**3.059,0**	-0,1%
2016	1.152,2	1.266,1	255,6	213,2	117,7	21,6	37,8	**3.064,0**	0,2%
2017	1.183,3	1.289,9	255,8	213,6	117,8	21,6	37,8	**3.119,7**	1,8%
Incremento anual acumulativo (%)									
17/16	2,7%	1,9%	0,1%	0,2%	0,0%	0,0%	0,0%	1,8%	-
17/12	0,1%	0,3%	2,1%	0,1%	0,0%	-1,5%	23,5%	0,5%	
17/07	0,3%	2,1%	0,9%	0,0%	0,3%	-0,8%	11,2%	1,1%	

Unidades: Megavatios (MW).

Fuente: Dirección General de Industria y Energía. Gobierno de Canarias

Figure 6 Generation configuration in the Canary Islands in 2017, by islands per MW

Tabla 3.1.2. Configuración del parque de generación de cada isla según potencia eléctrica. Año 2017

Fuentes de energía primaria	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro	Canarias
PRODUCTOS DERIV. PETRÓLEO								
Centrales térmicas	999,2	1.046,5	232,3	187,0	105,3	21,2	14,9	2.606,4
Refinería	-	25,9	-	-	-	-	-	25,9
Cogeneración	24,9	39,2	-	-	-	-	-	64,1
Total prod. derivados petróleo	**1.024,1**	**1.111,6**	**232,3**	**187,0**	**105,3**	**21,2**	**14,9**	**2.696,4**
FUENTES RENOVABLES								
Eólica (1) (2)	118,9	60,2	13,4	13,1	7,0	0,4	0,0	212,8
Fotovoltaica (1)	40,4	115,3	8,1	13,5	4,6	0,04	0,03	182,0
Minihidráulica	-	1,2	-	-	0,8	-	-	2,0
Hidroeólica	-	-	-	-	-	-	22,8	22,8
Biogás (vertedero)	-	1,6	2,1	-	-	-	-	3,7
Total fuentes renovables	**159,3**	**178,3**	**23,5**	**26,6**	**12,4**	**0,4**	**22,9**	**423,4**
TOTAL	**1.183,3**	**1.289,9**	**255,8**	**213,6**	**117,8**	**21,6**	**37,8**	**3.119,7**

Valores en bornes del alternador. (1) Sólo instalaciones conectadas a red. (2) No se contempla la potencia eólica asociada a la central hidroeólica de El Hierro.

Unidades: Megavatios (MW). Fuente: Dirección General de Industria y Energía. Gobierno de Canarias

Figure 7 Generation mix in the Canary Islands in 2017, by islands per MW

Tabla 3.1.3. Estructura tecnológica del parque de generación que utiliza productos petrolíferos en Canarias, y desglosado por islas. Año 2017

	Tecnología	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro	Canarias
Centrales térmicas	Turbina Vapor	280,0	240,0	-	-	-	-	-	520,0
	Motor Diésel	84,0	84,0	169,8	107,9	82,8	21,2	14,9	564,6
	Turbina Gas	173,5	265,7	62,5	79,1	22,5	-	-	603,3
	C. Combinado	461,7	456,8	-	-	-	-	-	918,5
Refinería	Turbina Vapor	-	25,9	-	-	-	-	-	25,9
Cogeneración	Turbina Vapor	24,2	-	-	-	-	-	-	24,2
	Motor Diésel	0,7	2,2	-	-	-	-	-	2,9
	Turbina Gas	-	37,0	-	-	-	-	-	37,0

Unidades: Megavatios (MW). Valores en bornes del alternador
Fuente: Dirección General de Industria y Energía. Gobierno de Canarias

Figure 8 Generation groups installed in thermal power plants as of December 31, 2017 Province of Santa Cruz de Tenerife

Central	Grupo	Nº	Pot. neta unitaria (kW)	Pot. bruta unitaria (kW)	Pot. neta total (kW)	Pot. bruta total (kW)
LA PALMA						
Los Guinchos	Diésel 6, 7 y 8	3	3.820	4.320	11.460	12.960
	Diésel 9	1	4.300	5.040	4.300	5.040
	Diésel 10 y 11	2	6.690	7.520	13.380	15.040
	Diésel 12	1	11.500	12.300	11.500	12.300
	Diésel 13	1	11.200	12.300	11.200	12.300
	Diésel 14 y 15	2	11.500	12.600	23.000	25.200
	Gas móvil 2	1	21.600	22.500	21.600	22.500
Total La Palma		**11**			**96.440**	**105.340**

Figure 9 Evolution of the maximum power demanded on each island

Tabla 3.2.11. Evolución de la potencia máxima demandada en cada isla

Año	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro
Potencia máxima de demanda bruta							
1995	363,0	315,0	72,3	43,3	26,1	6,3	3,4
1996	373,0	331,0	76,2	46,5	27,6	6,9	3,6
1997	403,0	352,0	84,9	53,9	27,6	7,3	3,7
1998	425,0	380,0	91,0	58,3	30,6	7,9	3,9
1999	447,0	409,0	96,1	63,2	31,4	8,6	4,1
2000	482,3	422,5	102,2	70,4	34,3	9,2	4,3
2001	498,7	477,6	111,6	78,3	33,8	9,7	4,9
2002	525,1	514,0	123,8	85,5	35,0	10,5	5,0
2003	547,0	523,0	134,2	89,8	39,7	11,5	5,8
2004	578,9	545,5	137,8	103,8	41,6	12,5	6,0
2005	601,1	584,8	140,9	118,9	42,8	11,5	6,4
2006	621,9	604,5	145,9	122,4	46,0	12,2	6,9
2007	637,0	627,9	148,0	127,3	47,0	12,0	7,3
2008	615,0	616,4	145,9	119,4	47,3	12,6	7,8
Potencia máxima de demanda neta							
2005	571,9	561,6	135,9	114,9	40,8	11,1	6,3
2006	588,2	577,1	141,1	118,1	43,8	11,7	6,7
2007	600,4	600,4	142,7	122,0	44,9	11,6	7,0
2008	580,7	585,1	139,3	115,3	44,9	12,1	7,5
2009	581,8	598,4	142,1	117,0	49,3	12,1	7,8
2010	576,9	578,7	143,1	119,0	49,9	12,5	7,6
2011	576,9	573,5	143,0	111,8	49,9	12,2	7,7
2012	573,0	581,5	144,1	113,5	48,3	12,2	7,8
2013	553,0	547,0	140,0	111,0	42,0	11,5	8,6
2014	549,0	547,0	139,0	111,0	42,1	11,3	7,7
2015	562,0	551,0	141,0	114,0	43,9	12,3	7,7
2016	547,0	549,0	140,0	118,0	45,7	11,7	8,1
2017	553,0	560,0	141,0	122,0	45,8	12,2	8,0
Tasa interanual de crecimiento de potencia máxima de demanda neta (%)							
17/16	1,1%	2,0%	0,7%	3,4%	0,2%	4,3%	-0,9%
17/12	-0,7%	-0,8%	-0,4%	1,5%	-1,1%	0,0%	0,5%
17/07	-0,8%	-0,7%	-0,1%	0,0%	0,2%	0,5%	1,3%

Unidades: Megavatios (MW)
Fuente: Unelco – Endesa (años anteriores a 2009) y Red Eléctrica de España (año 2009 y posteriores)

Figure 10 Maximum net power demanded on each island for months. 2017 year

Tabla 3.2.12. Potencia neta máxima demandada en cada isla por meses. Año 2017

Mes	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro
Enero	527,0	537,0	128,0	104,0	41,1	10,7	6,8
Febrero	539,0	523,0	127,0	101,0	40,7	10,7	6,9
Marzo	524,0	515,0	124,0	102,0	41,2	10,8	6,9
Abril	507,0	503,0	121,0	101,0	39,0	11,0	6,7
Mayo	493,0	499,0	117,0	98,0	38,8	10,2	6,4
Junio	516,0	531,0	124,0	107,0	38,8	10,3	6,9
Julio	528,0	537,0	129,0	113,0	41,2	11,0	7,0
Agosto	533,0	549,0	138,0	117,0	43,2	12,0	7,2
Septiembre	536,0	539,0	132,0	111,0	41,3	10,6	6,8
Octubre	548,0	555,0	136,0	116,0	41,7	11,1	6,7
Noviembre	530,0	540,0	130,0	110,0	40,4	10,5	6,5
Diciembre	526,0	539,0	135,0	110,0	44,8	11,9	6,7

Unidades: Megavatios (MW)

Fuente: Red Eléctrica de España (REE)

Figure 11 Maximum net power demanded time and date on each island for months. 2017 year

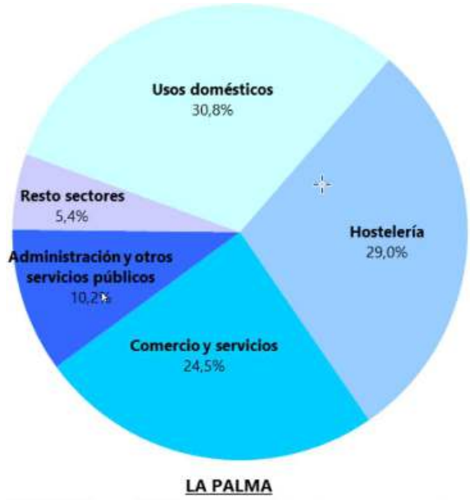
Tabla 3.2.13. Potencia neta máxima demandada en cada isla. Año 2017

	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro
Potencia	553,0	560,0	141,0	122,0	45,8	12,2	8,0
Fecha	17 oct.	17 oct.	07 ago.	24 ago.	24 dic.	18 ago.	03 ago.
Hora	20:41	20:36	13:52	20:45	19:47	21:56	20:36
Índice Cobertura (*)	1,60	1,80	1,50	1,30	2,10	1,50	1,40 (***)
Índice Cobertura (**)	1,50	1,40	1,30	1,30	1,90	1,50	1,40 (***)

(*) Se calcula este índice de cobertura con la potencia instalada el día de la punta máxima. (**) Se calcula este índice de cobertura con la potencia disponible el día de la punta máxima. (***) No se incluye la potencia hidráulica. En la generación instalada no se ha considerado la generación eólica ni la fotovoltaica (se consideran todos los grupos convencionales).

Unidades: Megavatios (MW). Fuente: Red Eléctrica de España (REE)

Figure 12 Percentage distribution of electricity demand by sectors in La Palma



Performing the same analysis for each of the Islands, although each of them shows a different distribution, they are similar in all cases, repeating, although in different order and percentage, the four sectors with the highest demand: "uses domestic ","administration and other public services", "hospitality" and "trade and services", with the only particularity of La Palma and El

Hierro, which incorporate among these four sectors to agriculture, livestock, forestry, hunting and fishing.

According to information provided by the distribution companies operating in the archipelago, the Canary Islands distribution network, as of 31 December 2017, has 7,279 kilometres of electrical line lines having a voltage of 20 kV or more and less than 66 kV.

Figure 13 Distribution network in the Canary Islands December 31, 2017

Tabla 3.6.1. Red de distribución existente en Canarias a 31 de diciembre de 2017. (Líneas eléctricas)

Isla	Tendido aéreo		Tendido subterráneo		Total
	km	%	km	%	km
Gran Canaria	1.040	43,5%	1.350	56,5%	2.391
Tenerife	1.096	44,0%	1.392	56,0%	2.488
Lanzarote	221	30,9%	494	69,1%	715
Fuerteventura	351	39,7%	534	60,3%	885
La Palma	320	70,9%	132	29,1%	452
La Gomera	140	66,8%	69	33,2%	209
El Hierro	71	50,9%	68	49,1%	139
Canarias	**3.239**	**44,5%**	**4.040**	**55,5%**	**7.279**

Fuente: Endesa Distribución Eléctrica S. L. y DEPCSA, (datos a julio de 2018)

Electric power transmission network development in La Palma is promoted via New Las Breñas – Valle de Aridane 66 kV and New Las Breñas 66 kV substation.

Figure 14 Electric power transmission network development in La Palma

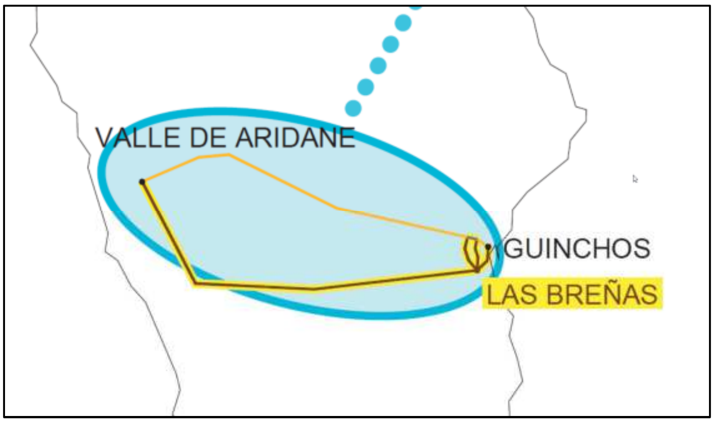


Figure 15 Evolution of the electricity transmission network of the Canary Islands

Tabla 3.5.3. Evolución de la red de transporte de energía eléctrica de Canarias

Año	Líneas (1) Longitud (km)		Cable submarino Longitud (km)		Subestaciones (2)			Capacidad de transformación (MVA)	
	≤66 kV	220 kV	66 kV	220 kV	66 kV	132 KV	220 kV	132 kV	220 kV
2009	1.072	163	15	-	48	0	4	0	1.375
2010	1.126	163	15	-	49	0	5	0	1.375
2011	1.126	163	15	-	49	0	5	0	1.375
2012	1.126	163	15	-	49	0	5	0	1.625
2013	1.126	163	15	-	49	0	5	0	1.625
2014	1.126	163	15	-	49	0	5	0	1.875
2015	1.131	216	15	-	50	0	5	0	2.000
2016	1.134	220	15	-	51	0	6	0	2.000
2017	1.135	220	15	-	54	3	7	560	2.000

(1) Incluye líneas aéreas (entre ellas la línea "Los Guinchos – Mulato" a 20 kV, en La Palma), enlaces submarinos y tramos subterráneos.

(2) Las subestaciones con dos parques de tensión 220/66 KV, 132/66 KV se contabilizan como subestaciones diferentes.

Fuente: Red Eléctrica de España (REE)

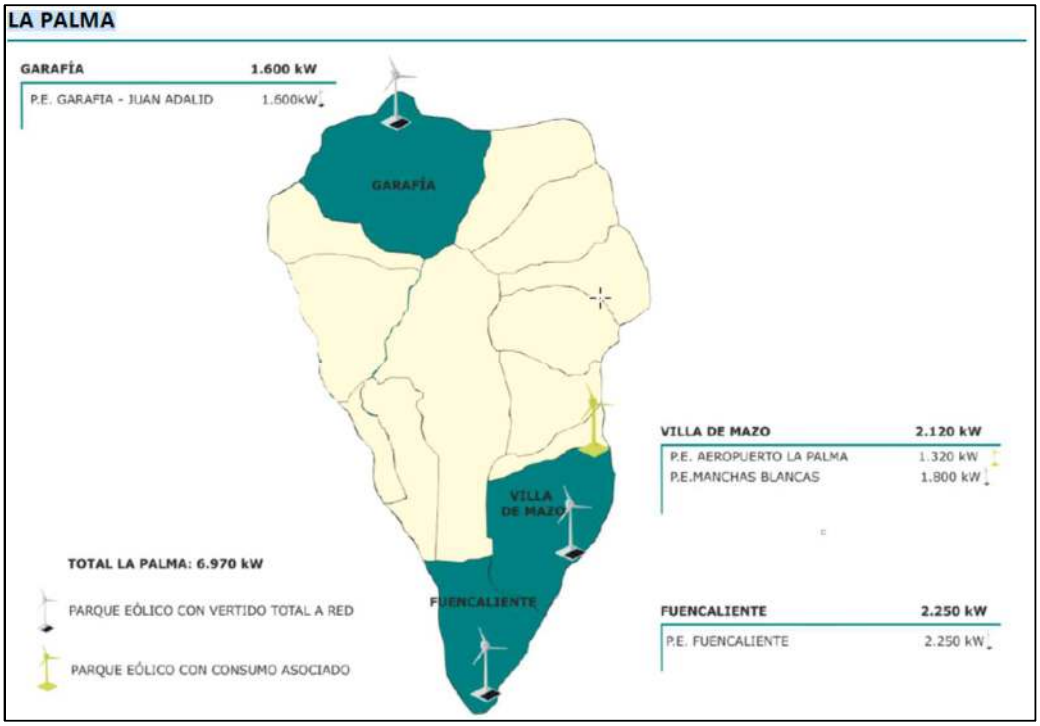
Figure 16 Electrical substations as of December 31, 2017. La Palma

Tabla 3.5.8. Subestaciones eléctricas a 31 de diciembre de 2017. La Palma

	Subestación	Tensión (kV)	Municipio
LA PALMA			
1	LOS GUIN1CHOS	66	BREÑA ALTA
2	VALLE	66	LLANOS ARIDANE

Fuente: Red Eléctrica de España (REE)

Figure 17 Geographical distribution of wind farms



3. Description of the project actions of the lines

Following circuits and substation are planned to be expanded in the La Palma island [3]:

- 66kV Las Breñas L / Guinchos-Aridane Valley (Double Circuit): The existing circuit at 66kV Guinchos-Aridane Valley and circuits at 66kV Guinchos-Las Breñas and 66kV Las Breñas-Aridane Valley
- 66kV Guinchos - Las Breñas 2 (Simple Circuit).
- 66kV Las Breñas - Aridane Valley 2 (Simple Circuit)

The basic structure of the power line consists of conductive cables, grouped in two groups of three phases each group constituting a circuit, through which the electricity, and some supports that support the phases, keeping them separate from the ground and each other.

In a generic way, the particularities of each line depend on their tension, which conditions, among other things the dimensions of its elements, dictated by the Regulation of High Voltage Aerial Power Lines (RLAT) according to Royal Decree 223/2008 of February 15. The main technical characteristics are the following.

- System: Three phase alternating current
- Frequency: 50 Hz
- Nominal voltage: 66 kV
- No. of circuits: One Double Circuit line and 2 Simple Circuit lines
- Number of conductors per phase: One (simplex)
- Conductor type: LARL 280 HAWK Aluminum and steel braided cables 21.8 mm, diameter 281.1 mm2 section
- Insulation type: Rubber-silicone compound type insulators
- Supports: Lattice Metals
- Foundations: Monobloc and 4 separate mass concrete legs
- Grounded: Closed rings of decarburized steel
- Ground wire: 1 or 2 earth-optical composite guard cables of diameter between 15 and 18 mm
- Approximate length: Approx. 20 km

The above mentioned length is preliminary and the final length will be confirmed after the study of corridor alternatives and the layout of the path in the hall of least impact.

Supports

In the design of these facilities, metal supports are provided for double and single circuit, each of the phases being composed of a conductor (simplex configuration). His height is defined by the RLAT in its Complementary Technical Instruction-LAT-07, depending on of various criteria, among which the minimum distance that must exist from the driver stands out to the ground in the case of maximum vertical arrow. Although the minimum distance for 66 kV is set at 6 m, Red Eléctrica adopts in its projects, for greater safety, a distance of 7 m, which it will be superior in crossings with roads, other power and telecommunications lines, etc., using in each case the distances indicated by the RLAT. The total height of the type supports double circuit

[3] https://www.ree.es/sites/default/files/04_SOSTENIBILIDAD/Documentos/tramitacion_ambiental/DI/DI-Guinchos-Brenas-Valle-JUL2016.pdf

will be approximately 36.5 m (free height 22 m), except in those exceptional cases that have to use supports with greater height.

The single circuit type supports will be similar to the double circuit supports with a reinforced configuration. The double circuit line will be equipped with 2 guard wires and the single circuit lines with 1 or 2 Guard cables depending on telecommunications needs.

The average distance between the towers is of the order of 300 to 400 m, being able to reach 700 – 900 m depending on various variables, among which the orography and the existing vegetation stand out.

The width of the crossings of the supports is between 7.74 and 10.24 m. The basis of the Tower is composed of four feet, with a separation between them of 5.00 and 9.00 m.

Ground wires-OPGW

They are located at the top of the installation, along its entire length, constituting an electrical extension of the grounding of the supports in order to protect the Lightning conductors and atmospheric discharges. Due to the smaller section of the cables land, there may be a risk of collision in some areas for some species of birds, for what can be signalled with anti-collision devices, called bird guards, which increase the visibility of these cables.

Foundations

The foundations of the supports will be mass concrete mass monobloc or legs apart.

Conductors

The conductors are made up of twisted aluminium and steel cables and have about 21.8 mm in diameter. The driver used will be LARL 280 HAWK, of 281.1 mm2 section. The minimum distance between the conductors and their accessories in tension and the supports will not be less than 0.7 m (Del). However, the line has been designed maintaining a distance to mass with drivers at rest of 1.5 m, in order to facilitate the manoeuvres of possible work of maintenance in tension and to avoid that the electrocution of birds takes place.

Imposed easements

In the case of the line under study, it will be attempted to run through areas where the easements generated by the installation are minimal, limited to the corresponding land occupation to the base of the towers, and to an easement that, in the case of non-public land, does not prevents the owner from fencing, planting or building on it, leaving said servitude safe. The easement has been respected when the fence, plantation or building built by the owner do not affect the content of the easement and the security of the installation, people and goods.

Information on the base grid configuration and parameters are obtained[4] as below. Hawk conductor is used for the existing OHLs similar to the planned one. Typical values have been considered for the unit and distribution transformers.

[4] https://energia.gob.es/planificacion/Planificacionelectricidadygas/desarrollo2015-2020/Documents/Planificaci%C3%B3n%202015_2020%20%202016_11_28%20VPublicaci%C3%B3n.pdf

Figure 18 Main technical characteristics of the existing OHLs

REF.	ISLA ORIGEN	ISLA FINAL	SUBEST. ORIGEN	SUBEST. FINAL	kV	Cto	ACTUACIÓN	LONGITUD km total km (cable)	CAPACIDAD DE TRANSPORTE		FECHA Alta/Baja	MOTIVACIÓN									OBSERVACIONES	PLAN 2008-2016
									Inv	Ver		RRTT	SdS	Fiab	Int	ATA	EvCo	EvRe	Alm	ApD		
	La Gomera	Tenerife	EL PALMAR	CHIO	66	1	Nuevo enlace submarino	42	50	50	2020				X						Características a definir en los estudios técnicos de detalle	2016
	La Gomera	Tenerife	EL PALMAR	CHIO	66	2	Nuevo enlace submarino	42	50	50	2020				X						Características a definir en los estudios técnicos de detalle	2016
TIC-11	La Palma	La Palma	GUINCHOS	LAS BREÑAS	66	1	Alta E/S Línea-Cable	1 (.5)	80	80	2019		X				X			X		
TIC-11	La Palma	La Palma	LAS BREÑAS	VALLE DE ARIDANE	66	1	Alta E/S Línea-Cable	20 (1)	42	42	2019		X				X			X		
TIC-11	La Palma	La Palma	GUINCHOS	VALLE DE ARIDANE	66	1	Baja E/S Línea-Cable	20 (.7)	42	42	2019		X				X			X		
TIC-11	La Palma	La Palma	GUINCHOS	LAS BREÑAS	66	2	Nuevo Cable	1	80	80	2019		X									
TIC-11	La Palma	La Palma	VALLE DE ARIDANE	LAS BREÑAS	66	2	Nueva Línea-Cable	20 (5)	80	80	2019		X									

Tables in below show the values of single-phase short-circuit intensity and three-phase short-circuit fault of the two 66 kV substations of La Palma according to three characteristic scenarios of the demand recorded in 2017: peak, medium and low[5]. These values are approximately confirming the results of the short circuit calculations.

Figure 19 Short circuit levels in the existing configuration

Tensión (kV)	Nudo	Icc trifásico (kA) 2017	Icc trifásico (kA) 2016	Icc monofásico (kA) 2017	Icc monofásico (kA) 2016	X/R 2017
66	Guinchos	2.4	2.4	3.3	3.3	2
66	Valle Ariadne	1.8	1.8	2.3	2.3	2

Tabla 1. Valores de cortocircuito del sistema eléctico de La Palma. Escenario Punta. Año 2018

Tensión (kV)	Nudo	Icc trifásico (kA) 2017	Icc trifásico (kA) 2016	Icc monofásico (kA) 2017	Icc monofásico (kA) 2016	X/R 2017
66	Guinchos	1.6	1,6	2.3	2.3	2
66	Valle Ariadne	1.3	1.3	1.7	1.7	2.1

Tabla 2.Valores de cortocircuito del sistema eléctico de La Palma. Escenario Llano. Año 2018

Tensión (kV)	Nudo	Icc trifásico (kA) 2017	Icc trifásico (kA) 2016	Icc monofásico (kA) 2017	Icc monofásico (kA) 2016	X/R 2017
66	Guinchos	1.2	1.2	1.7	1.7	2.1
66	Valle Ariadne	1	1	1.4	1.4	2.1

Tabla 3. Valores de cortocircuito del sistema eléctico de La Palma. Escenario Valle. Año 2018

1. Associated cost of new Las Breñas 66kV 36MVA installation: 2.7M€
2. Associated cost of existing Valle de Aridane 66kV 18MVA modification: 0.7M€
3. Associated cost of 12.1MW generation in Las Breñas 66kV: 1.34M€

- **VALORACIÓN ECONÓMICA**

El coste total estimado para esta actuación asciende a: *23,3 M€*

5 https://www.ree.es/sites/default/files/01_ACTIVIDADES/Documentos/AccesoRed/InformeAnual_Evolucion_Corriente_Cortocircuito_SEC_2018.pdf

Existing Cost-benefit Analysis

As stated in the current Energy Planning for 2015-2020, the transport network on the island of La Palma is constituted by a single axis between the Aridane and Guinchos Valley substations, the latter being a critical substation for the system. To avoid situations that affect the quality of the electricity supply on this island, the creation of the new Las Breñas node and a new east-west axis are proposed.

It is called the new axis Las Breñas-Valle de Aridane 66 kV and is included in the planning in the following terms:

1. New Las Breñas 66 kV substation and Las Breñas in / out at Guinchos-Valle de Aridane 66 kV
2. New Las Breñas 66 kV substation (switch and a half).
3. Entrance / exit of Las Breñas in Guinchos-Valle de Aridane 66 kV.
4. New line Guinchos-Las Breñas 66 kV
5. New Aridane Valley line-Las Breñas 66 kV
6. Adaptation to the operation procedure of the Guinchos 66kV substation

The function that will be fulfilled by the new installation in the electrical system is

1. to guarantee the quality and safety of the electricity supply (SdS) on the island of La Palma
2. ordinary evacuation (EvCo)
3. support for distribution and demand for Big consumers (ApD).

In the studies carried out in the transmission network planning process, the failure of the current Aridane Valley circuit Ginchos 66 kV would cause the loss of supply of the demand that hangs from the 66 kV Valley of Aridane node. In the most unfavourable cases, the total supply of the island could be lost, as in the incident that occurred on September 3, 2013, where there was a total zero on the island, leading to a loss of supply of 32 MW.

Thus, the network that feeds the island of La Palma, fails to comply with the basic criteria of security of supply and suitability of the Transport Network (POSEIE 1 and POSEIE 13) according to which the system must support simple contingencies (N-1) without affecting the quality and security of supply, and therefore the construction of the facilities indicated in this document is of vital importance to guarantee the quality and safety of the electricity supply on the island of La Palma. Without such facilities, the system will be exposed to any partial or total power outages in this area.

Thus, the network that feeds the island of La Palma, fails to meet the basic criteria of security of supply and suitability of the Transportation Network (POSEIE 1 and POSEIE 13) according to which the system must support simple contingencies (N-1) without affecting to the quality and security of supply.

An estimate of the ENS (Energy Not Supplied) has been made in the area that would mean the non-realization of the network proposed in this report. Assuming the unavailability of the current circuit Aridane-Guinchos Valley 66 kV of about 40h / year (according to statistics of unavailability of the last 8 years), an ENS of 510MWh is estimated that valued at € 6,350 / MWh (reference ENTSOE) gives a cost Estimated annual ENS avoided by the € 3.24 M project.

The analysis carried out allows estimating the social profitability of the development action of the Transportation Network by calculating the economic indicators:

- Internal Rate of Return (IRR) = 10%.
- Investment Recovery Period (PR) = 10 years

Technical Analysis of the new 66kV Line

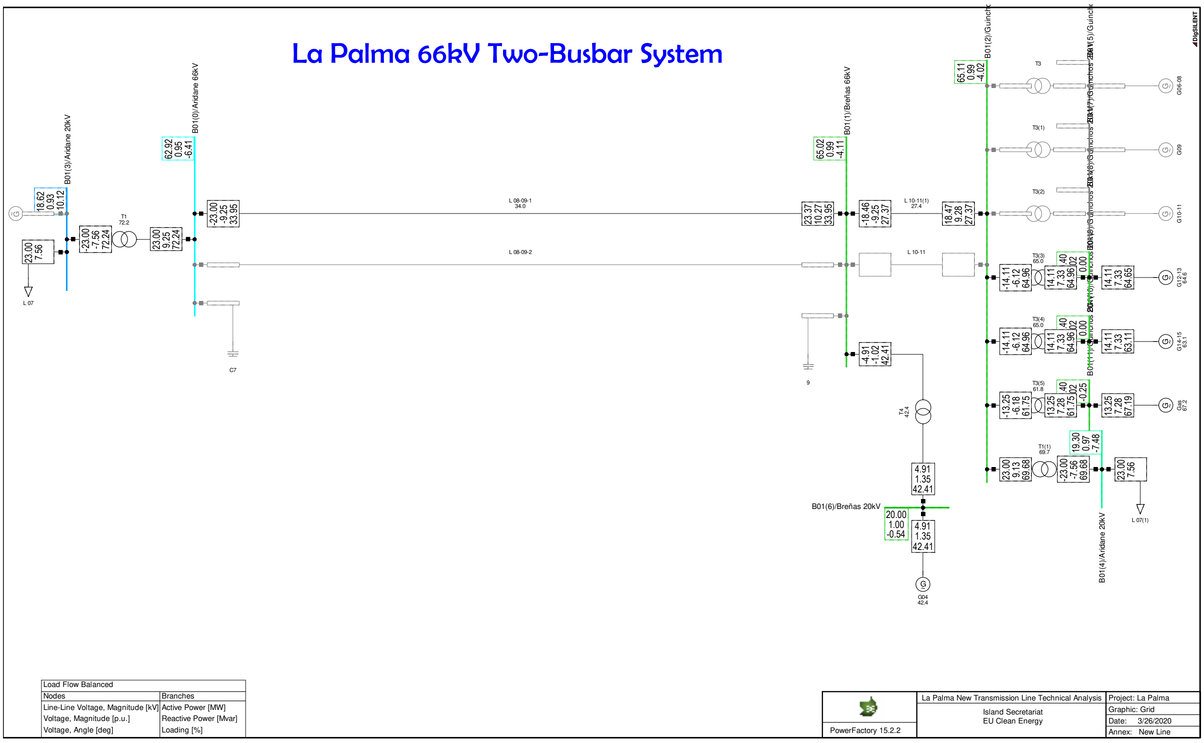
Techno-Economical Calculation can be applied to costs and benefits analysis of network expansion using the Net Present Value (NPV). Investment costs, interruption costs, cost of losses, and the economic impact of project timetables are basically investigated in the economical calculation analyses. In the available calculations, only the interruption costs and investment costs have been considered. However, different non-monetizable and monetizable economic and technical aspects could be investigated in the transmission expansion planning analysis, such as, maximum power transfer limits, system losses, N-1 contingency, fault currents, transient stability, and low frequency ossifications.

4. Load Flow Impact Analysis

Load flow results in base case and upgraded case are presented in Figure 20 and Figure 21, respectively. In the assumed operational point at maximum load, voltage setpoint of the committed generations are fixed at 1.02 p.u. Neither tap changer nor reactive compensators are used in the calculations. Three units of Guinchos generation plant are scheduled to serve the load. Slack busbar is assumed as dispatched balancing load and generation through distributed slack by synchronous generation units.

As it is shown in Figure 20 and Figure 21, without the new 66kV transmission line, under voltage condition occurs in Aridane 20kV busbar. Although this issue could be solved via activating the tap changer of primary transformer, addition of the planned 66kV overhead line improves the voltage profile of the grid. As it was expected, loading level and power losses of the transmission grid is decreased via the expansion of the grid with Aridane-Breñas and Breñas-66kV new transmission line.

1. Benefits of the new planned line are summarized as below:
2. Reduced grid active and reactive losses
3. Better power factor of generation units
4. Better voltage profile
5. Lower loading of transmission lines
6. Higher available transfer capability



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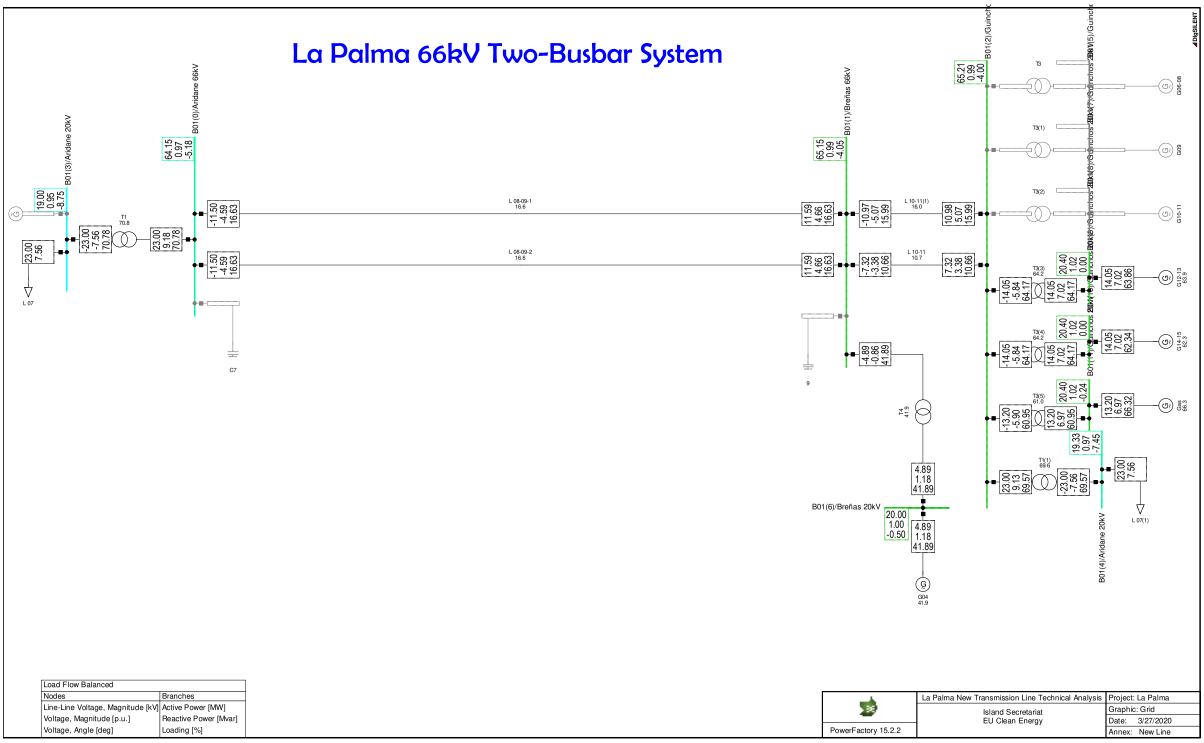
|------------------------------------------------------------------------------------------------------------------|
| Total System Summary                          | Study Case: Study Case                  | Annex:            / 1  |
|------------------------------------------------------------------------------------------------------------------|
|                                                                                                                  |
| No. of Substations   12      No. of Busbars      12      No. of Terminals    168      No. of Lines          2    |
| No. of 2-w Trfs.      6      No. of 3-w Trfs.     0      No. of syn. Machines  4      No. of asyn.Machines  0    |
| No. of Loads          2      No. of Shunts        0      No. of SVS            0                                 |
|                                                                                                                  |
| Generation         =     46.38  MW          23.29  Mvar      51.90  MVA                                         |
| External Infeed    =      0.00  MW           0.00  Mvar       0.00  MVA                                         |
| Load P(U)          =     46.00  MW          15.12  Mvar      48.42  MVA                                         |
| Load P(Un)         =     46.00  MW          15.12  Mvar      48.42  MVA                                         |
| Load P(Un-U)       =      0.00  MW          -0.00  Mvar                                                         |
| Motor Load         =      0.00  MW           0.00  Mvar       0.00  MVA                                         |
| Grid Losses        =      0.38  MW           8.17  Mvar                                                         |
| Line Charging      =                        -0.24  Mvar                                                         |
| Compensation ind.  =                         0.00  Mvar                                                         |
| Compensation cap.  =                         0.00  Mvar                                                         |
|                                                                                                                  |
| Installed Capacity =     80.16  MW                                                                              |
| Spinning Reserve   =     33.78  MW                                                                              |
|                                                                                                                  |
| Total Power Factor:                                                                                              |
|   Generation       =        0.89  [-]                                                                            |
|   Load/Motor       =  0.95 / 0.00  [-]                                                                           |
|------------------------------------------------------------------------------------------------------------------|
```

Figure 20 Load flow in Maximum load without the new line



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-----------------------------------------------------------------------------------------------------------------------
| Total System Summary                                   | Study Case: Study Case              | Annex:             / 1  |
-----------------------------------------------------------------------------------------------------------------------
|                                                                                                                       |
| No. of Substations    12        No. of Busbars       12        No. of Terminals     168        No. of Lines          4  |
| No. of 2-w Trfs.      6         No. of 3-w Trfs.     0         No. of syn. Machines  4         No. of asyn.Machines  0  |
| No. of Loads          2         No. of Shunts        0         No. of SVS           0                                  |
|                                                                                                                       |
| Generation           =     46.18  MW          22.19  Mvar     51.24  MVA                                               |
| External Infeed      =      0.00  MW           0.00  Mvar      0.00  MVA                                               |
| Load P(U)            =     46.00  MW          15.12  Mvar     48.42  MVA                                               |
| Load P(Un)           =     46.00  MW          15.12  Mvar     48.42  MVA                                               |
| Load P(Un-U)         =     -0.00  MW          -0.00  Mvar                                                              |
| Motor Load           =      0.00  MW           0.00  Mvar      0.00  MVA                                               |
| Grid Losses          =      0.18  MW           7.07  Mvar                                                              |
| Line Charging        =                        -0.50  Mvar                                                              |
| Compensation ind.    =                         0.00  Mvar                                                              |
| Compensation cap.    =                         0.00  Mvar                                                              |
|                                                                                                                       |
| Installed Capacity   =     80.16  MW                                                                                  |
| Spinning Reserve     =     33.98  MW                                                                                  |
|                                                                                                                       |
| Total Power Factor:                                                                                                   |
|   Generation         =        0.90  [-]                                                                              |
|   Load/Motor         =  0.95 / 0.00  [-]                                                                              |
|-----------------------------------------------------------------------------------------------------------------------|
```

Figure 21 Load flow in Maximum load with the new line

5. N-1 Contingency Impact Analysis

Before transmission grid expansion in La Palma island with a new OHL in Guinchos-Aridane corridor, as it was expected, the grid is not able to meet N- security constraint. In the most adverse cases, the total supply of the island would be lost due to cascading events. After transmission expansion, the failure of the current Aridane Valley-Guinchos 66 kV circuit wouldn’t cause the loss of supply of the demand connected to the 66 kV Valley of Aridane node.

6. Short Circuit Impact Analysis

Three-phase and single-phase short circuit calculations have been conducted and compared for the base case and in presence of the new planned OHL using VDE standards. As it is shown in Figure 22 to Figure 25, both single-phase and short circuit currents and powers in Aridane substation have been increased due to less Thevenin Equivalent Impedance in presence of the new parallel line.

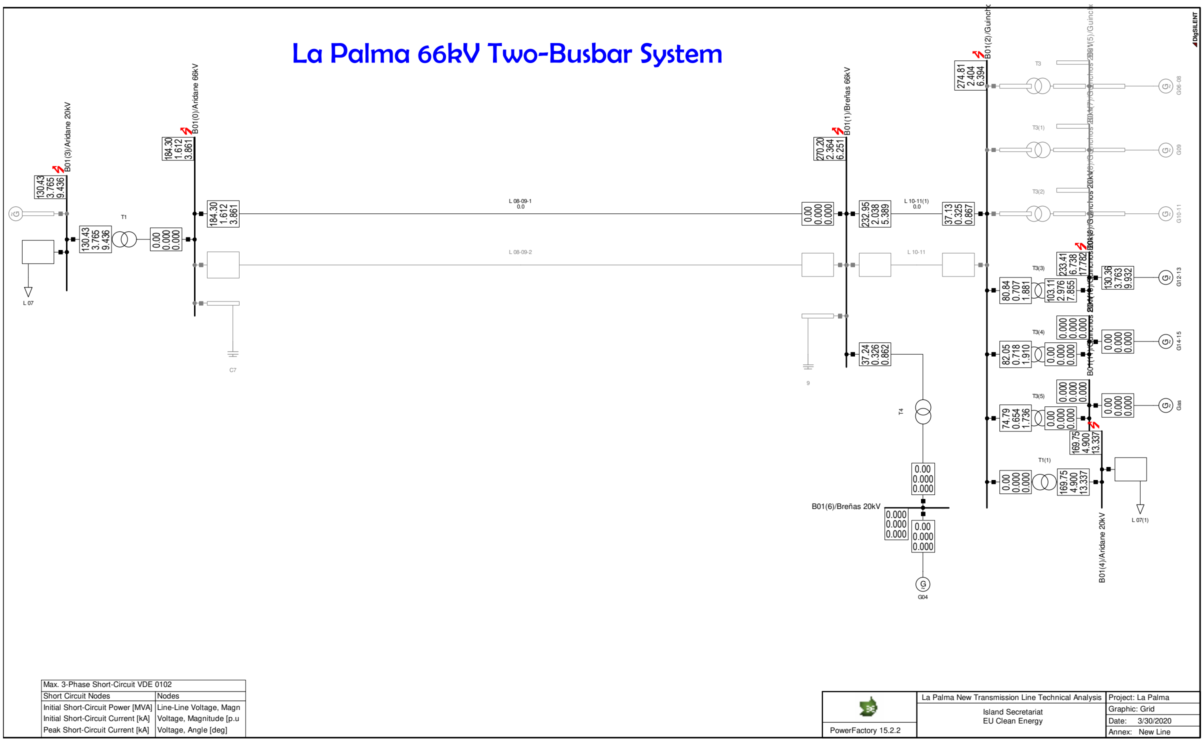

Figure 22 Short circuit in Maximum load without the new line

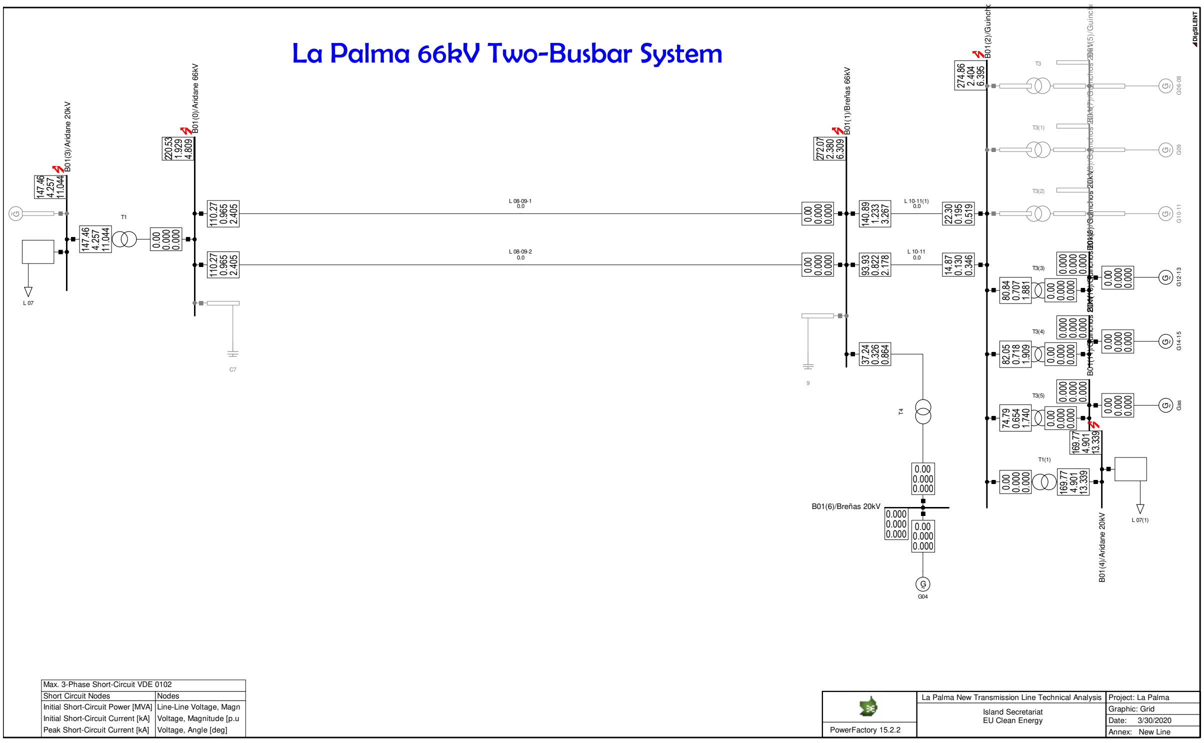

Figure 23 Short circuit in Maximum load without the new line

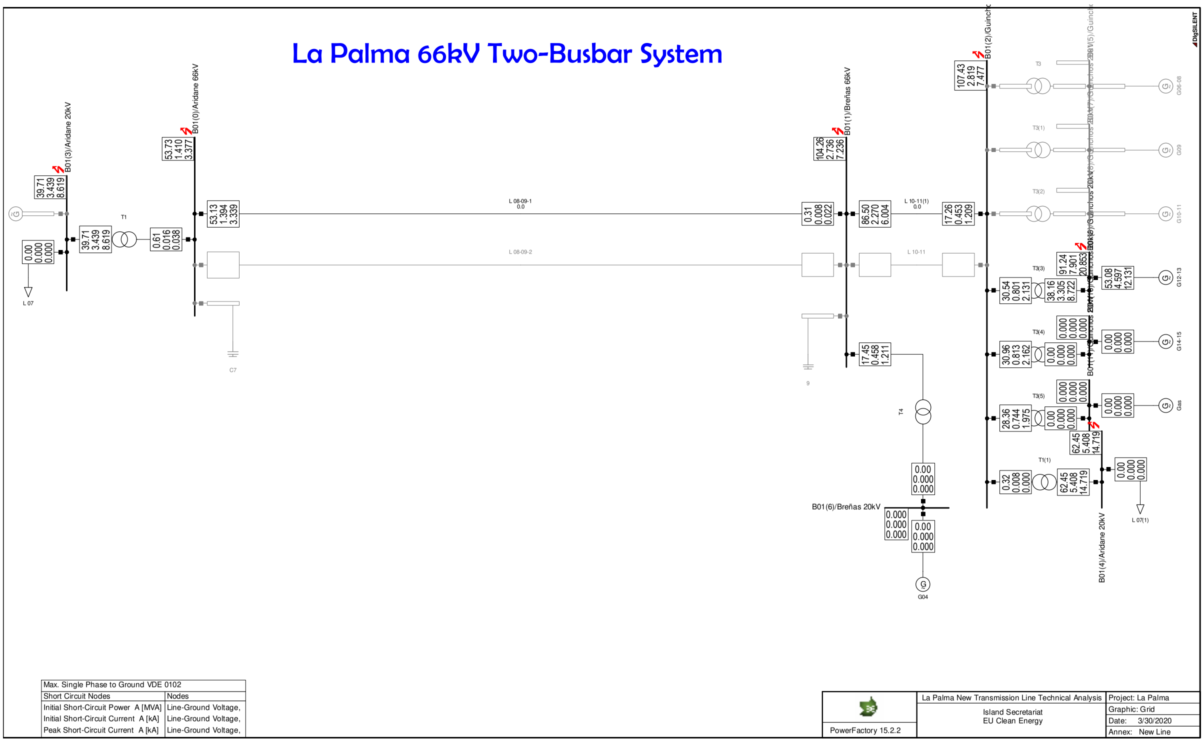

Figure 24 Single phase short circuit in Maximum load without the new line

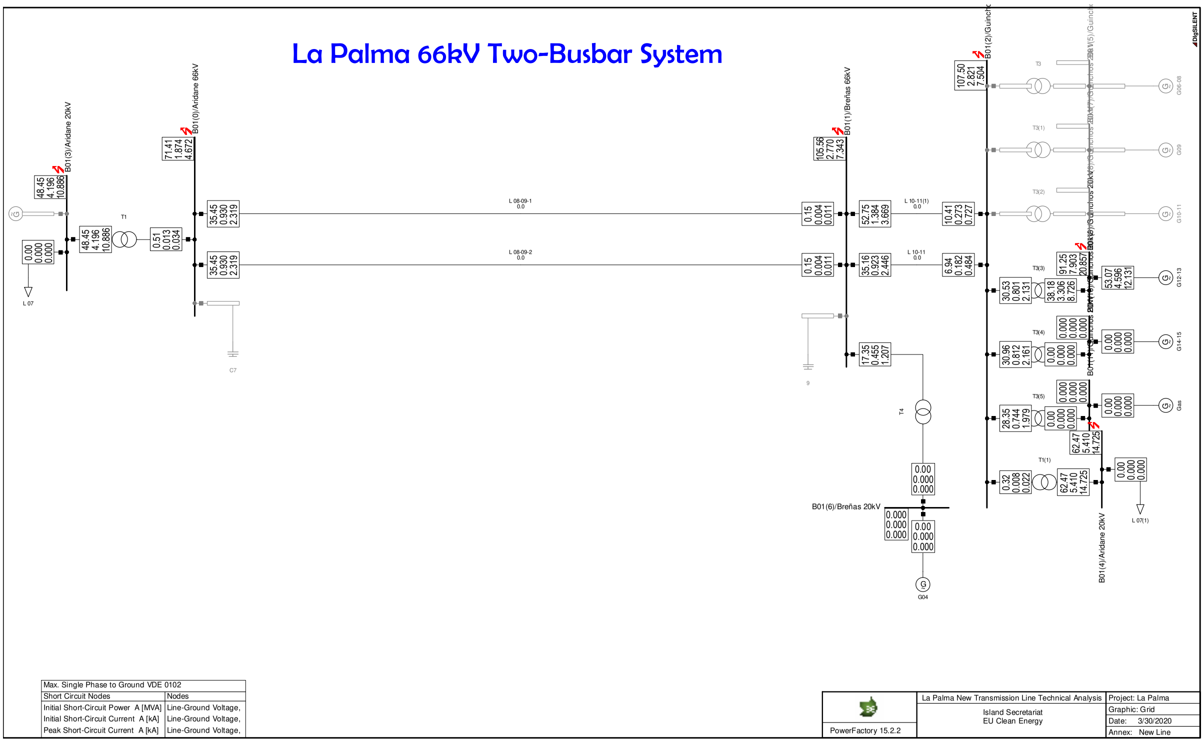

Figure 25 Single phase short circuit in Maximum load with the new line

Circuit breaker selection

Based on the following typical breaking capacity considered for each voltage level:

- 40 kA / 1 Sec for 225 kV
- 31.5 kA / 1 Sec for 110 kV
- 31.5 kA / 1 Sec for 60 kV
- 31.5 kA / 1 Sec for 33 kV

Short circuit currents after addition of the new OHL are in the range of a common circuit breakers in the relevant voltage level.

The short circuit alteration of the grid is small compared after expansion of the transmission corridor. Calculations show that for a three-phases fault and single phase to ground fault, all short circuit currents are below the rated breaking currents with a very large margin. It can be concluded that the new line does not have adverse and severe effect on the short circuit current/power levels and the selected circuit breaker would be sufficient in the new configuration.

Short circuit ratio (SCR)

To evaluate the system strength at the point of interconnection of inverter-based generation units (e.g., renewable resources), recently the concept of SCR is being widely used for this new application. SCR is defined the ratio of "short circuit capacity" of an AC power grid to the "MW renewable power injection" at the point of interconnection. The value of SCR shows if the power grid has the enough strength (capability) of absorbing a certain amount of renewable power without serious operational problems. With respect to the value of SCR a point of interconnection can be identified as strong, weak, or very weak. Figure below shows the threshold of (basic) SCR for estimating the system strength.

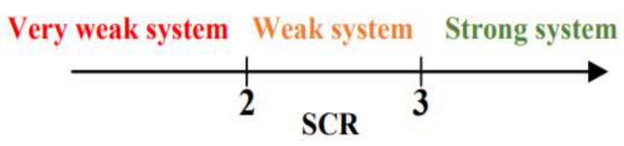

Figure 26 SCR values and PCC strength

SCR (short circuit ratio) at the POI of Ariadne 66kV is increased in presence of new 66kV OHL due to lower line impedance and higher short circuit power at Ariadne 66kV.

7. Stability Impact Analysis

Addition of the new line will reduce the impedance of the La Palma sub transmission grid. The popular view is that the grid impedance is adverse to the system stability specifically when renewable energy sources are connected to a weak grid[6]. System design primarily affects the amount of synchronizing power that can be transferred between two substations. Two substations connected by a low impedance circuit (after expansion) will probably stay synchronized with each other under all conditions except a fault on the connecting circuit, a loss of field excitation, or an overload. The greater the impedance between substations (before expansion), the less severe a disturbance will be required to drive them out of step. Dynamic stability of grid is improved by construction of the new connecting circuit. This means that from the standpoint of maximum stability, all synchronous machines should be closely connected to a common bus. This fantasy solution is impractical due to limitations on short-circuit obligations, economics, and the requirements of physical plant layout.

No information has been provided by the Client on the system dynamic parameters and controllers (Governor, AVR, etc.). Therefore, in this section impact of new planned line is analysed in an analytic manner without simulations.

Steady-State Stability (Power Transfer)

Despite the fact that the conversation in the remainder of this section spins around stability under transient and/or dynamic conditions, for example, faults, switching operations, etc., there ought to likewise be mindfulness that a power system can become unstable under steady state conditions. In case of La Palma island as a simple power system to which stability considerations apply consists of a pair of synchronous machines in Guinchos and Breñas, and the Aridane substation acting as a load including motors, connected together through a reactance. This reactance is the sum of the transient reactance of machines and the reactance of the connecting circuit. Losses in the machines and the resistance of the line could be neglected for simplicity.

In addition to the internal voltage of the generator(s) and motor(s), reactance(s) of the machines and transmission system affect the stability. Maximum real power that could be transmitted from the generator to the motor is the steady-state stability limit for the La Palma system. The lower the grid reactance, the greater the power that can be transmitted under steady-state conditions.

Addition of the parallel line in Guinchos-Aridane corridor will decrease the impedance and consequently, will approximately double up the maximum transfer power capability of the system.

[6] As a matter of fact, the increase of gird impedance can prevent the low-frequency oscillations (less than 50 Hz), while the increase of gird impedance deteriorates the high-frequency (more than 300 Hz) stability.

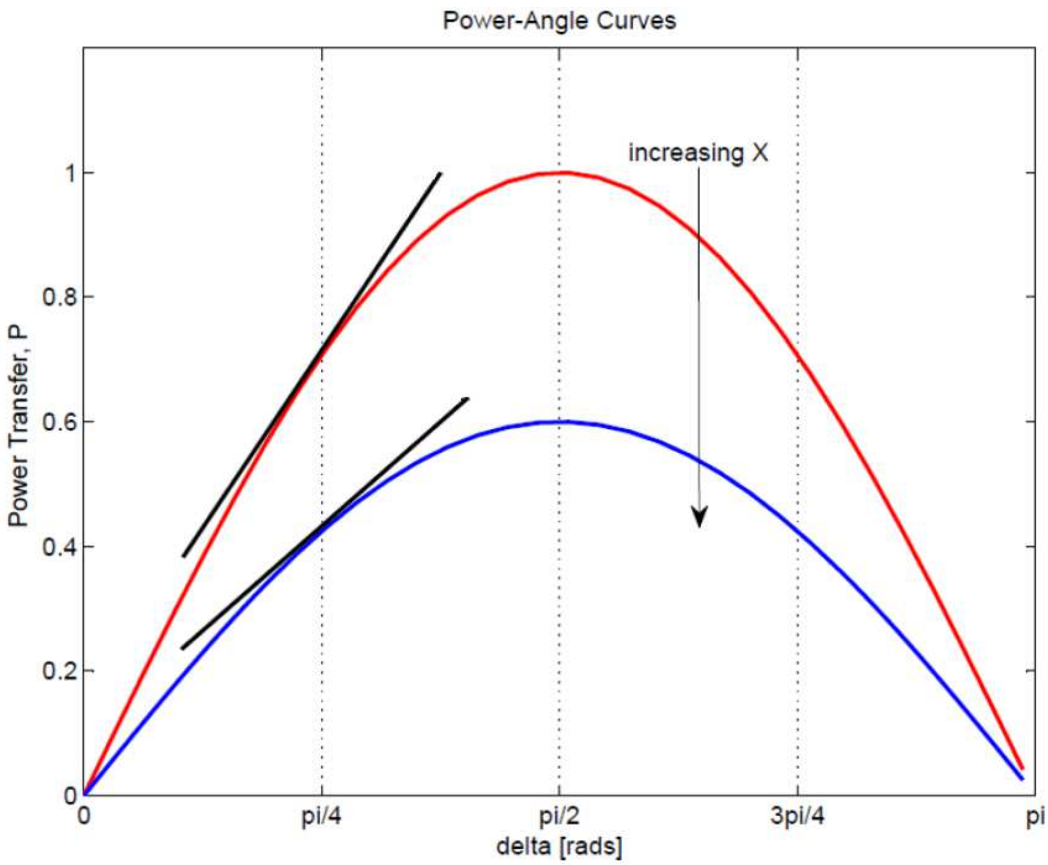

Figure 27 Power-Angle Curves of Single Machine-Infinity Bus system: effect of increasing X

Although, transient stability is affected by the same three electrical characteristics that determine steady-state stability limits, however, a system that is stable under steady-state conditions is not inevitably stable when endangered with a transient disturbance.

Transient Rotor Angle stability

Rotor Angle stability involves the analyses of electromechanical oscillations characteristic in power systems. It is well-defined as the capability of synchronous machines in an interconnected power system to continue operating in synchronism after being exposed to a disturbance. The appropriateness and adequacy of both damping and synchronizing torque components of each synchronous machine would determine the system stability. Series reactance of transmission networks has a significant impact on transient rotor angle stability of the system.

For a given operating point, the synchronizing torque coefficient, Ks, is given by the slop of the power angle curve at that point (Figure 27):

$$K_s = \frac{\partial P}{\partial \delta}$$

From Figure 27 and synchronizing torque coefficient equation, it is seen that the higher the power transfer, the higher is the synchronizing torque and hence the rotor angle stability. Thus, series reactance of the new transmission line would impact the grid transient stability.

Addition of the new line would improve the transient rotor angle stability through reducing series reactance of the grid. Time domain simulations of system are required to show the precise enhancement in three-phase faults on major plants and substations through evaluating the critical clearing time (CCT) with and without the new parallel 66kV line.

Small-signal stability

The impedance of the grid has an impact on the frequency of the dominant poles. For the existing and future configuration of La Palma transmission grid, the electrical distance between the Guinchos generation center and Aridane load center is an important factor to be considered for the system small signal stability and local/interarea oscillation frequencies. It is assumed that addition of the parallel line will reduce this distance electrically. The system is stable for the shorter electrical distance (after expansion), whereas the system may become unstable for a longer electrical distance (before expansion), owing to the reduced resistance, that is, damping. It means modes of the system moves to the left so that the grid have more damping in possible oscillation frequencies. In case of longer line (before expansion), the frequency of the dominant poles changes to the higher values and results in a significant harmonic.

Voltage stability

By using a stability index, i.e. the bus eigenvalue, the strength and robustness of a particular bus in a power system could be pointed out The eigenvalue echoes the change of the bus voltage magnitude matching to reactive power variations. A week bus has a small eigenvalue and is sensitive to a change. On the other hand, if the eigenvalue is large, the corresponding bus is strong and robust[7].

The robustness of a La Palma power system in voltage stability point of view can be determined and estimated based on its eigenvalues. The new configuration with larger eigenvalues has been found to be more stable in voltage stability standpoint. Similar conclusion has been realized through considering the effect of the expansion plan on the SCR.

[7] Tuan Ngo, Min Lwin, Surya Santoso, Power transmission expansion planning based on voltage stability indexes, 2017 IEEE Power & Energy Society General Meeting, Chicago, IL, USA.

8. Protection Impact Analysis

Principals

Transmission lines are exposed to short circuits between phases or from phase to ground. The range of the possible fault current, the effect of load, the question of directionality and the impact of system configuration are all part of the transmission line protection problem. La Palma sub-transmission grid may use four protection principles as following:

- Overcurrent (instantaneous overcurrent and inverse, time delay, overcurrent) (50, 51, 50N, 51N)
- Directional Overcurrent (67, 67N)
- Distance (21, 21N)
- Differential (87)

Overcurrent protection is the simplest and most economical of TL protection schemes. It is limited to radial lines. Considering the case of La Palma with a radial line supplying a load substation, the protection scheme must satisfy the following requirements.

- Under normal conditions the breakers are not tripped.
- Under fault conditions only the breakers closest to the fault on the source side are tripped.
- If the closest breaker fails to operate, the next breaker closer to the source should trip.

Protection system should be coordinated with respect to each other in order to provide the desired selectivity called "relay coordination". In discrimination by time (Time-grading), an appropriate time setting is given to each of the relays controlling the circuit breakers in a power system to ensure that the breaker nearest to the fault opens first. Overcurrent relay with definite time characteristic should be used via near-infeed higher tripping time method. In case of occurrence of fault near the source (Guinchos and Breñas substations) a large current will be produced and is very destructive if not remove quickly. With definite time characteristic the, heaviest faults are cleared slowly that may damage grid's components.

In the time – current grading method, the time – current grading is achieved with the help of relays that have inverse time – overcurrent characteristics requiring two settings for each relay: CTS (Current Tap Setting) and TDS. Time Dial Setting (TDS) is selected so that there is enough Coordination Delay Time (CDT). Coordination time delay is 0.4s in American standard and 0.5s in British standard.

By addition of the new line and substation to the grid, System's Thevenin Equivalent Impedance is reduced approximately to half causing higher short circuit currents in transmission overhead line and substation faults. Accordingly, protection setting of transmission components and distribution grid connected to Aridane substation should be altered as per the short circuit levels in the new configuration.

Impact of new transmission line

Every year the capacity of power systems is increasing, meaning that short circuit current levels are continuously going up like the case of La Palma after the new 66kV line's commissioning. The ratings of instrument transformers at many existing substations that were designed many years ago may now become underrated with present fault current levels. Such a situation would be obviously important to protection engineers who strive to ensure security and dependability of the protection is not jeopardized.

By installation of new transmission facility, transformers and generation, in the circuit model, the Thevenin equivalent impedance seen at system buses is decreased equivalently. Consequently, the fault current level is increasing, simply according to the Ohm's law (as seen in short circuit studies). The increased fault current causes the electrical devices to experience more thermal and mechanical stress. The protective relays are supposed to correctly operate to interrupt the fault current flowing through the protected equipment. However,

- relay misoperation,
- slow operation, and
- failure to operate

may be expected as the relay performance may be jeopardized in such scenarios.

The impacts of increasing short current on protective relays could be investigated in detail, in terms of:

- signal processing algorithms,
- relay clamping level, and
- CT saturation

which is beyond the scope of this project. Besides the risks of trivial CT saturation, which affects the security of the protection system, the concern is if a particular relay is capable of processing such high current, while maintaining adequate accuracy to ensure protection security and dependability. In higher short circuit level in the transmission grid of La Palma due to addition of new OHL, it can be concluded that:

On the clamping level:

- The clamp level will reduce the current magnitude and rms values, affecting protection functions that are related to the current magnitude or rms values.
- The current phasor angle is not affected by the clamping mechanism.
- There is no erroneous even harmonics resulted from the clamping mechanism. However, erroneous odd harmonics are induced.
- If the current samples surpass the clamp level, the larger fault current will result in the larger ratio of odd harmonics to fundamental magnitude for a constant clamp level and third harmonic.
- Particularly, the ratio of the fifth harmonic to fundamental may be used to prevent the transformer differential function during overexcitation conditions. Because of presence of the incorrect fifth harmonic induced by clamping; the transformer differential function may fail to operate on a severe fault. An instantaneous differential function with a well-considered pickup setting is helpful to avoid such situation and increases the relay dependability.

On the CT saturation:

- The CT saturation will reduce the magnitude and rms values, which affects protection functions that are related to the current magnitude or rms values.
- The CT saturation will result in the leading angle, which may affect directional functions. DC saturation will cause more leading angle shift compared to AC saturation with the same symmetrical fault level.

- Due to the distortion in waveforms, the ratio of harmonics to fundamental magnitude increases.

On the Combination of CT saturation and clamping level:

- As introduced before, the clamping level is used to flatten the high current input; however, the high fault current is subject to CT saturation. It should be studied that what happens if the saturated current is clamped.

Evaluation Techniques

Some techniques and methods to explain how to evaluate the effect of the increased fault current on the dependability and security of a specific system and relay are proposed as following:

- Test in a high current laboratory
- Test using a real time power system simulator
- Simulate in electromagnetic transient analysis software
- Playback recorded waveforms
- Program in a simple Excel spreadsheet

9. Alternatives

Why Storage as a Transmission Asset?

New network approaches are required for transmission expansion for the inevitable and escalating shift from reliance on conventional generators to high penetration of inverter-based generation. In order to supply the demand of La Palma with acceptable reliability as per the grid code, the expansion of transmission network is needed. In conventional approaches, transmission network expansion planning is supported by building new power lines. In the general case, as the installation of new lines may require facilities and/or authorizations that are not readily available and accessible, expansion cannot be completed immediately. In this case, energy storage systems and batteries in particular may be an alternative since they can reduce the need to procure excess capacity to deal with demand peaks, therefore avoiding unnecessary network expansion. Therefore, transmission companies may consider energy storage as the means to enhance transmission infrastructure. The main advantages of a properly sized and placed battery system in comparison with the traditional transmission expansion are:

- increasing system reliability
- increasing system transfer capability
- operator's faster timelines and
- less cost.

La Palma's transmission grid has a unique design. Transmission lines go from west to east, but do not complete the loop—meaning power can only flow both ways between west and east with the generation units mainly concentrated in the eastern part. This makes managing and operating a secure system that tries to minimize cost of generation very complex leading to significant price differences between the states and blocking renewable energy from being exported from specific pockets in the island.

In the studies carried out in the current planning process of the transmission network of La Palma, the outage of the current Aridane-Guinchos Valley circuit 66 kV would cause the loss of supply of the demand hanging from the Aridane Valley knot 66 kV. The planned transmission expansion aims to add redundancy to the critical transmission infrastructure for reducing network interruption cost and increasing reliability so that it has significant impacts across the economy and social welfare. However, this transmission redundancy would be barely used due to typical high availability and low failure rate of the overhead lines. Likewise, this capacity is not needed for the normal operation according to the capacity of the existing line and the maximum power needed to be transferred.

Bearing in mind the high renewable generation policy of the island, if a coal plant is retired for economic reasons in high penetration of renewables or when it reaches the end of its life, the planned transmission lines may be beneficial anymore**.** In contrast with new transmission lines, battery systems are much easier to install, and they have already shown some economic benefits for the transmission upgrade deferral[8]. There are also several applications for the energy storages when they are not used for the main application which in this case is the reliability improvement in the transmission line outage circumstances. The optimal placement, type and size of BESSs are still open issues that need to be defined for stressed power systems.

[8] A. Malhotra, B. Battke, M. Beuse, A. Stephan, T. Schmidt, Use cases for stationary battery technologies: a review of the literature and existing projects, Renew. Sustain. Energy 56 (2016) 705–721.

Some Battery-based transmission projects

Battery-based transmission projects already being planned in Germany, France, India and the U.S[9].

- The first 40 MW "virtual transmission line" project by French utility RTE is already planned with the purpose of increasing grid integration of renewable energy and optimizing electricity currents on its network.
- 1.3 GW of energy storage has been proposed in the German grid development plan, to ensure grid stability and lower network costs.
- Between 250 and 500 MW of energy storage has been proposed in India, to add capacity on its transmission network. An innovative cost recovery mechanism that includes assigning the costs between renewable developers and distribution companies that have an obligation to serve load.
- As one of the first projects planned to provide congestion relief in U.S. markets, a 10 MW energy storage project is planned in the Pacific Gas & Electric as a transmission solution. In addition, the U.S. PJM market—the largest power market in the world—in the last year received proposals for multiple 25-50 MW battery-based storage projects to help relieve network congestion issues.

Providing levels of scalability and millisecond-range responsiveness

One of the main objectives to be achieved in island in future is that at certain times, the energy is produced exclusively from renewable sources. In this case, the contribution of resources with a fast response becomes very important for frequency regulation. Battery-based energy storage as a transmission asset offers a wide arrangement of advantages over traditional infrastructure:

1. Allowing transmission utilities to use existing lines more effectively without having to invest in new lines to increase capacity;
2. Battery-based solutions are modular and can be scaled and relocated in future to fit the needs;
3. Battery-based energy storage has response times in the millisecond range, which means that fewer megawatts will be needed to ensure balance on the network;
4. Deploying battery-based storage is far less troublemaking and therefore more attractive than the grid expansion;
5. Storage can be deployed in just one to two years at the 100+ megawatt scale, compared to other upgrade options that typically take a minimum of two to three years to implement.

Battery as a transmission expansion option is a concept whose time has come—especially in La Palma, where grid load and generation conditions are not changing quickly year-to-year but the renewable penetration. Deploying energy storage as a transmission resource gives the utilities an opportunity to build a next-generation electricity network—providing new levels of network flexibility and helping ensure customers' access to reliable, cost-effective and green power.

Although there are different technological alternatives for energy storage implementation[10], as per the orography of the La Palma island, pumped hydro energy storage (PHES) is very

[9] [Available online]: https://blog.fluenceenergy.com/australia-energy-storage-solutions-transmission-asset

[10] Rodrigues EMG, Godina R, Santos SF et al (2014) Energy storage systems supporting increased penetration of renewables in islanded systems. Energy 75:265–280

interesting. However, it doesn't mean that this technology is suitable for all the applications like transmission planning. In order to increase the renewable share in Canary Islands the PHES has been included in the energy development strategy as the most important energy storage technology[11]. However, there are other technologies and ways of storing the energy, such as the use of a fleet of electric vehicles (EVs) managed by an aggregator as a commercial middleman agent between the system operator and plug-in electrical vehicles. Besides, the EV is able to perform other tasks in order to support the electric system, providing security and stability to the network[12]. Nevertheless, coordinated management when these vehicles are being charged is an essential aspect to maintain the security of the electric system during high-demand hours.

It would be suggested to analyse the effects of the introduction of two possible alternatives as a way of energy storage: pumped hydro storage and electric vehicles in La Palma island. For this, a simulation model adapted to the features of La Palma should be used considering different scenarios. The installation of an additional renewables supported by pumped hydro storage and electric vehicles, would allow the current share of renewables to increase. Furthermore, this would mean a reduction in CO2 emissions, costs of generated kWh and fuel-based energy dependence.

[11] Bueno C, Carta JA (2005) Technical-economic analysis of windpowered pumped hydrostorage system, part II: model application to the island of El Hierro. Solar Energy 78(3):396–405
Portero U, Vela´zquez S, Carta JA (2015) Sizing of a wind-hydro system using a reversible hydraulic facility with seawater: a case study in the Canary Islands. Energy Convers Manag 106:1251–1263
Padro´n S, Medina JF, Rodrı´guez A (2011) Analisys of a pumped storage system to increase the penetration level of renewable energy in isolated power system, Gran Canaria: a case study. Energy 36(12):6753–6762
Martinez-Lucas G, Sarasu´a JI, Sa´nchez-Ferna´ndez JA´ et al (2016) Frequency control support of a wind-solar isolated system by hydropower plant with long tail-race tunnel. Renew Energy 90:362–375
Politica Energe´tica en Canarias, Horizonte (2030) Centro Atla´ntico de Pensamiento Estrate´gico (CAPTE).
[12] Bessa RJ, Matos MA (2010) The role of an aggregator agent for EV in the electricity market. In: Proceedings of the 7th Mediterranean conference and exhibition on power generation, transmission, distribution and energy conversion (Med-Power'10), Agia Napa, 7–10 Nov 2010, 9 pp
Marrero GA, Perez Y, Petit M et al (2015) Electric vehicle fleet contributions for isolated systems: the case of Canary islands. Int J Automot Technol Manag 15(2):171–193

10. Conclusion

As per the load flow studies, system voltage and loading profile are improved by addition of the new 66kV parallel OHL. N-1 security constraint is met by addition of the new line. Increase of the short circuit level in Aridane substation after addition of new 66kV OHL would increase the SCR resulting in stronger point of interconnection. The increase of short circuit current does not jeopardise the circuit breakers selection and rating values.

A system is less likely to have stability problems if the generators are electrically close together after addition of the new 66kV OHL. Sometimes the stability problem will go away after the construction of a new transmission line, the reconfiguration of the utility supply, or some other system change. Lowering system impedances will reduce the electrical distance of the generation units and establish a stronger tie between co-gen and utility systems. The effectiveness of reducing impedances to increase system stability can be determined easily using modern computer programs.

Further studies would be suggested to investigate the impact of the planned OHL on the system protection setting and adjustment. It would be suggested to analyse economically and technically the effects of the introduction of two possible alternatives as a way of energy storage: pumped hydro storage and electric vehicles in La Palma island.

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