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Wind power integration improvement in an island by installing battery energy storage systems. Case study of Lanzarote-Fuerteventura.

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Abstract

Some small isolated power systems have a grid infrastructure weakly meshed and stability could be seriously affected when a large amount of renewable energy is being flowed into the grid.

In this paper critical clearing time (CCT) is studied along with the increase in renewable energies integration. This study considers the use of squirrel cage induction generators (SCIG) wind turbines.

Battery energy storage systems (BESS) have been considered in order to overcome this kind of power system drawbacks. Thus, renewable energy integration improvement is achieved. Renewable energy improvement is analyzed by means of CCT values.

Dynamic analysis is performed in order to determine CCT values taking into account voltage, system frequency and the amount of load shedding.

Keywords

Wind power, isolated power system, battery energy storage systems, critical clearing time, transient stability

1. Introduction

Nowadays, power systems must be evaluated in order to ensure an adequate integration of renewable energies. To contribute to this progressive change in the energy model, Spanish Transmission System Operator (TSO) Red Eléctrica de España (REE), is carrying out a major investment plan to ensure a more secure, efficient and sustainable electricity supply in power systems of the Canary Islands [1]. One of the most important is the development of energy storage systems to be used as system operation tools to improve the stability and security of the Canary power systems.

The small insular power systems have features such as a grid infrastructure weakly meshed or low system inertia which offer less robustness than the continental power systems. These features and those inherent in the renewable sources influence stability when a large amount of renewable generation is connected to the grid.

Europe designed its own energy strategy based on three pillars: environment, internal energy market and security of energy supply. Each country has designed its strategy to meet the objectives 20-20-20 by 2020, which aims to reduce greenhouse gases by 20%, 20% increase in renewable generation and 20% improvement in energy efficiency. This energy policy has fostered a greater presence of renewable generation in all European countries [2].

Likewise, Renewable Energy and Energy Efficiency for the Sustainable Development of West Africa and Islands of Macaronesia (ENERMAC) project promotes the creation of a network of excellence in the field of renewable energies and energy efficiency [3]. ENERMAC is developed around three key targets: energy planning, the rational use of energy, and the analysis of the electricity grids and microgrids.

This study is a part of a Master thesis carried out in University Institute of Intelligent Systems and Numeric Applications in Engineering (SIANI), University of Las Palmas de Gran Canaria (ULPGC) [4]. The study focuses on the ENERMAC third objective, specifically in power system studies [5].

Battery energy storage systems (BESS) could improve the integration of the renewable energies into these small isolated power systems. Therefore, BESS have been considered in this study.

In this connection, nowadays there are some projects:

- Energy Storage for Commercial Renewable Integration (ESCRI) [6];
- Tesla battery storage system in California [7];
- Almacena Project by REE [8];
- G.R.A.C.I.O.S.A Project by Endesa [9];
- Store Project is led by Endesa Generación, S.A [10].

In this study is analyzed, in the first instance, the difficulties presented by small isolated power systems for integrating an appreciable amount of wind power generation. After that, a solution based on BESS is examined for the improvement of this type of power system with wind generation.

Therefore, potential of BESS has been examined to:

- contribute to voltage and frequency control of the power system;
- contribute to increase the use of renewable generation within the network;
- improve the quality of electricity supply.

All these objectives focus on the analysis of the operation of the storage system in an isolated power system along with the integration of renewable energies.

Thus, Lanzarote-Fuerteventura power system expected by 2020 is considered in this paper as an example of small and isolated power system.

2. Methodology

As it be mentioned before, Lanzarote-Fuerteventura power system expected by 2020 is used in order to study the wind power integration and BESS performance using Critical Clearing Time (CCT). This power system is formed by Lanzarote island power system and Fuerteventura island power system.

Lanzarote-Fuerteventura power system expected by 2020 presents two power plants: Punta Grande in Lanzarote Island and Las Salinas in Fuerteventura Island. Transmission network considers lines and substations with 66kV and 132kV voltage levels. Both islands are linked by two submarine power cables with 190MVA of total capacity.

Different study cases of this power system with gradual increase of wind power were studied. This increase of wind power was from 10MW to 150MW, in steps of 10MW.

Dynamic analysis for several duration of three-phase short circuit events were performed for these study cases.

CCT values are obtained by the evaluation of the Lanzarote-Fuerteventura power system behavior on each study case. Analysis focused on different variables such as voltage, system frequency and load shedding over the simulation time.

These three-phase short circuits with specific durations were studied at different selected buses:

- Punta Grande (Lanzarote) power plant such as PV bus.
- Las Salinas (Fuerteventura) power plant such as slack bus.
- Haría-Teguise bus and Jandía bus (farther buses).
- Corralejo bus (bus in between both power plants)

This study considers squirrel cage induction generator (SCIG) wind turbines, one of the most widely-used type of wind turbine.

BESS have been also considered in similar cases of wind power increased as has mentioned before. Two 3MW/9MWh BESS have been modelled. One battery installed at the Tuineje bus (Fuerteventura) and another one at Callejones bus (Lanzarote). These BESS are capable to provide active power-frequency (P-f) and reactive power-voltage (Q-V) controls.

3. System Modeling

Analyzed small isolated power system is that on Lanzarote-Fuerteventura power system expected by 2020 [11].

Conventional synchronous generators, SCIG wind turbines, transformers, transmission lines, protections relays and loads are modeled to bring about dynamic simulations of the power system.

Modeling of the conventional generation units includes the generator and also a turbine-speed governor and an excitation system.

Validated modeling has been used for the configuration of BESS [12]. A simplified diagram of this configuration it can be seen in figure 1.

BESS control algorithm is modeled with the use of three of the modules in the generic renewable model list, namely [12] [13]:

(1) regc_a – the renewable energy generator/converter model, version a;
(2) *reec_c* – the renewable energy electrical controls model, version c;

(3) *repc_a* – the renewable energy plant controller, version a.

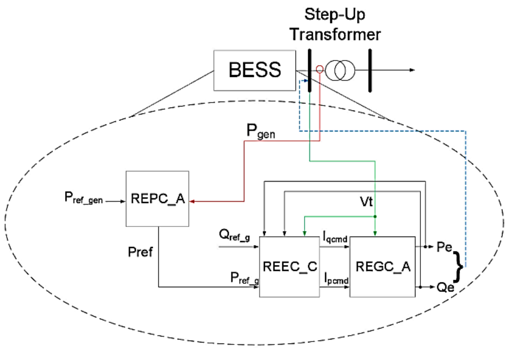


Figure 1. BESS configuration using the generic renewable dynamic models [12]

A Single-line diagram of the modeled Lanzarote-Fuerteventura power system expected by 2020 can be seen in figure 2.

Modeling and analysis were performed using PowerWorld Simulator-Version 20 [14].

4. Simulation

The renewable power integration, based on wind turbines, and the effects of the BESS have been evaluated by means of CCT.

CCT can be seen as a measure of the transient stability of a power system and it can be defined as the maximum allowed duration of a three-phase short circuit before:

(1) loss of system stability;
(2) or an unacceptable value of load shedding;
(3) or unacceptable parameters values in the subsequent steady state [11].

Spanish TSO has used the CCT parameter to design the protection systems of the power transmission network. As usual, an unacceptable value of load shedding considered in this paper is 10% of connected load [15].

Equations (1) and (2) were considered when carrying out simulations. Equation (1) is the swing equation of the synchronous machine.

$$\frac{d\omega}{dt} = \frac{1}{2H}(P_m - P_e) \qquad (1)$$

Where $\frac{d\omega}{dt}$ is the rotor acceleration, H is the inertia constant, P_m is the mechanical power and P_e is the electrical power.

Active power is the real part of the complex power and it is shown in Equation (2).

$$P_e = Re(\bar{V}\bar{I}^*) \qquad (2)$$

BESS in the power flow analysis has been initialized with the same voltage as the bus in which they are installed. With this, the battery does not inject or consume active or reactive power in the initial steady state.

5. Results and Discussion

Figure 3 presents the CCT values obtained for each study case. It can be seen results with and without connected BESS. In all cases, unacceptable values of load shedding established the CCT.

As a part of the results, voltage and system frequency time evolutions when a three-phase short circuit takes place at Corralejo bus are shown in figure 4.

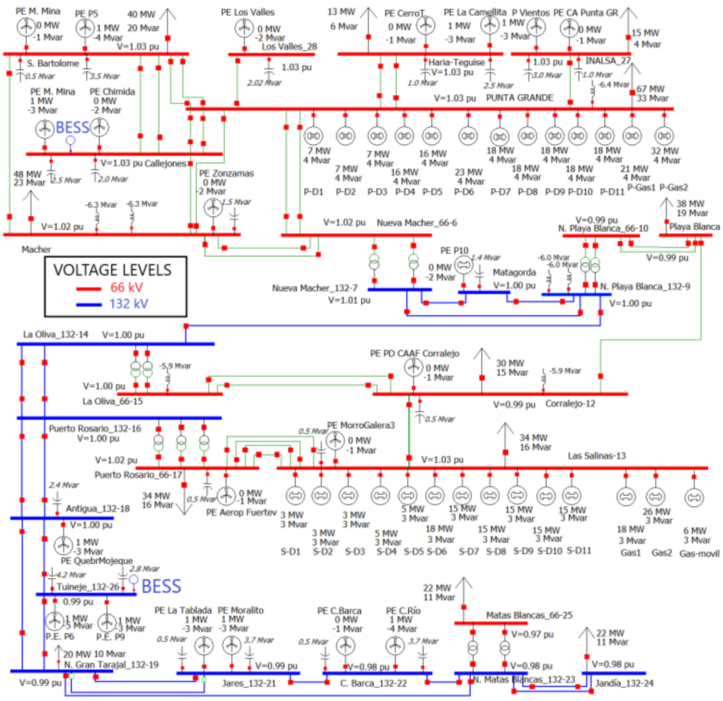


Figure 2. Lanzarote-Fuerteventura power system expected by 2020

When a short circuit occurs, system frequency increases its value. This is due to a decrease in P_e according to equation (2). As a consequence, an imbalance between P_m and P_e takes place. Therefore, $\frac{d\omega}{dt}$ and system frequency raise its values.

When the short circuit is cleared, system frequency diminishes, due to the recovery of the voltage which implies the raise up of P_e. This raising of P_e causes an imbalance in swing equation of opposite sign to the previous one. Synchronous generators reduce its rotational speed and system frequency diminishes.

When the short circuit is cleared, also an overvoltage could take place. This would be given by over-excited synchronous generators which generate more reactive power to compensate voltage dips during the short circuit, as illustrated in figure 4.

Excessive deviations of system frequency or network voltages could cause wind farm outages by the trips of its protections relays.

In the case of severe wind farm outages, system frequency deviations are higher and setting values of the load shedding relays are reached, getting the CCT value when 10% of the system load is tripped.

Short circuit at Jandía bus is a special case. Jandía is the farthest bus from any power plant and during the short circuit occurs.

In this manner, P_e grows giving rise to a higher imbalance on generation and power consumption.

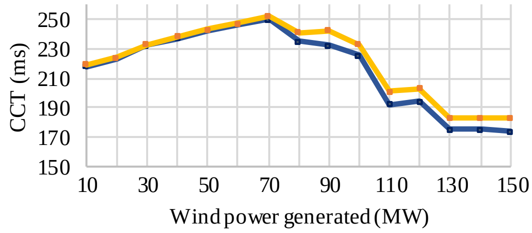
In the studied case, CCT values generally rise up for injected wind power growing from 10 to 70MW (Figure 3). This is related to the fact that there is a reactive power consumption that wind farms absorb after the short circuit is cleared, for compensating the previous demagnetization during the short circuit. This consumption causes a lower growth in the values of the voltages just after short circuit is cleared, improving CCT values in these study cases.

However, the reduction of system inertia causes a decrease in the CCT values rapidly from 80 MW. In Equation (1) it can be seen that by decreasing H, the system is less robust. This reduction of system inertia occurs due to the replacement of conventional generation by wind power.

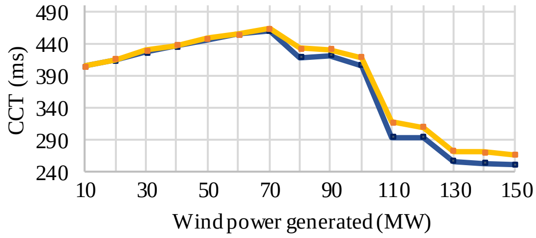
With the aim of improving this, the study presented in this paper shows an improvement of CCT values bring about by the effects of BESS. Therefore, an improvement of the wind power integration could be expected.

An example of obtained time evolutions of voltage, system frequency and active and reactive power are shown in figure 5 for a case in which two BESS have added to the power system, as introduced before in section 2.

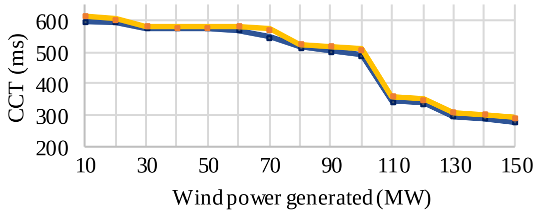
During a short circuit, both BESS inject reactive power when the voltage is decreasing and consume active power when over frequency occurs. In the same way, it absorbs reactive power when the voltage is increasing and active power is generated when frequency is decreasing.



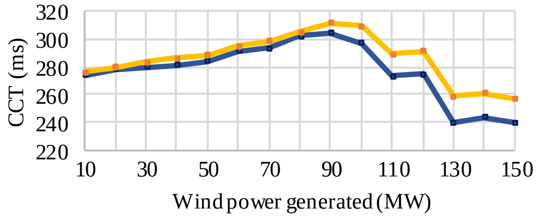
a) Punta Grande bus



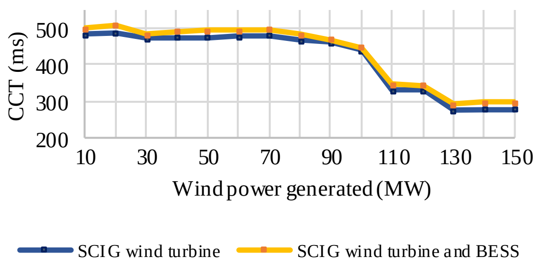
b) Haría-Teguise bus



c) Jandía bus

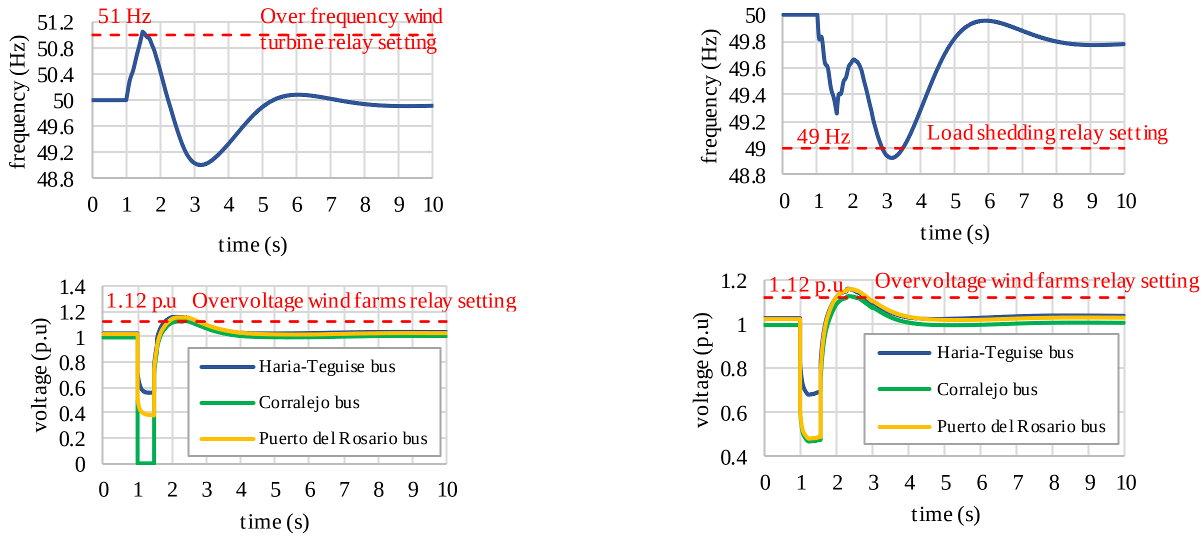


d) Las Salinas bus



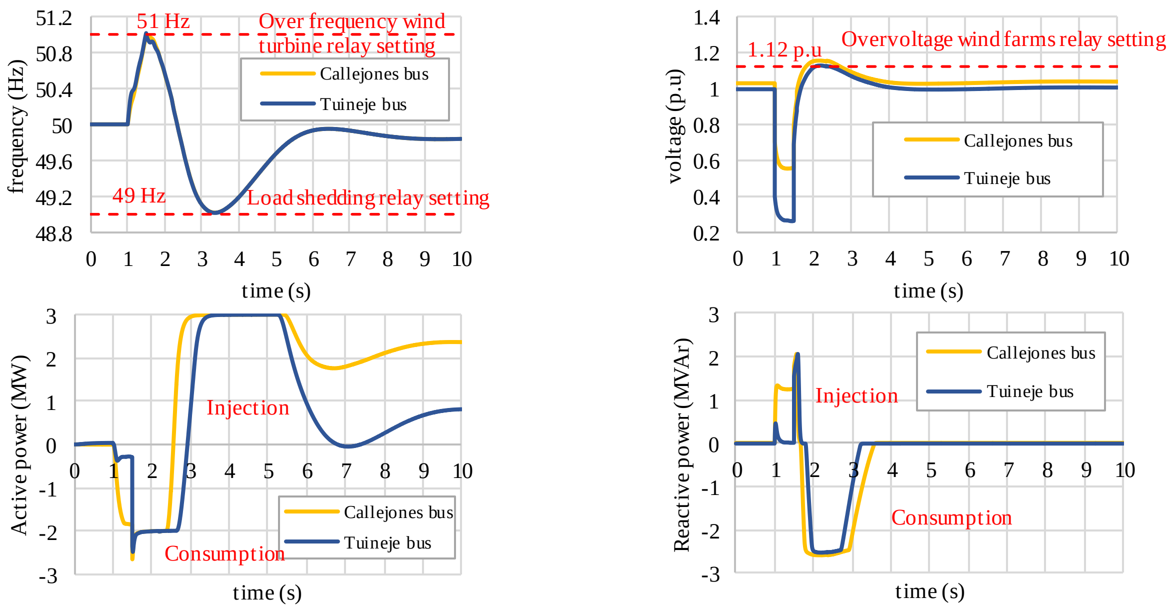
e) Corralejo bus

Figure 3. Critical clearing time values obtained



a) Corralejo bus. 10MW power generated   b) Jandía bus. 60MW power generated

Figure 4. Time evolution of voltaje and system frequency for a three-phase short circuit at Corralejo and Jandía bus



a) BESS P-f control   b) BESS Q-V control

Figure 5. Time evolution of voltage, system frequency and active and reactive power of BESS when a three-phase short circuit takes place in Corralejo bus

It can be seen that the capability of Q-V control of BESS relieves the under and over voltages. Furthermore, its P-f control produces a mitigation of over and under frequency. As a result, disconnection of wind power and load shedding events are reduced. Therefore, the CCT values are higher, as it can be seen in figure 3, increasing the wind penetration level.

6. Conclusions

This paper presents an analysis of wind power integration into isolated power systems considering Battery Energy Storage Systems (BESS). Analysis was carried out with a Lanzarote-Fuerteventura power system model. Wind power integration and BESS performance have been quantified with Critical Clearing Time (CCT).

It has been observed that an increase in the integration of the wind energy affects system stability if a short circuit occurs. Stability has been quantified with the values obtained from CCT, obtaining higher values with the incorporation of BESS.

A three-phase short circuit causes a voltage dip and system frequency rises. When the short circuit is cleared, an overvoltage takes place and the frequency value drops below the rated value. Because of this kind of small and isolated power system, overall voltage dip and subsequent overvoltage occur due to its weakly meshed infrastructure. This means that stability is seriously influenced when a large amount of renewable energy is connected along of the power system.

Wind farm outages are observed in several cases. These outages are caused by trip of over frequency and overvoltage protection relays of the wind farms. Wind farm outages are followed by a greater frequency deviation and it causes load shedding. As a consequence, CCT values are diminished.

Besides, as more wind power integration, a smaller number of conventional generators are connected. Therefore, inertia constant of power system is also smaller. Consequently, CCT also diminishes due to these smaller power system inertia values.

The system frequency and voltage deviations caused by the three-phase short circuit is diminished by the installation of BESS. For this reason, there is also an improvement in CCT values which means that wind power integration is improved.

This improvement is due to that, during the short circuit, the BESS injects reactive power making the bus voltage not drop as much. In addition, reactive power is consumed after the short circuit, reducing the voltage growth of the bus, avoiding in some cases the overvoltage which causes disconnection of wind farms. Therefore, the BESS Q-V control provides stability to the electric power system since it avoids so much disconnection of wind farms.

On the other hand, BESS P-f control consumes active power in the beginning of the three-phase short circuit. This causes the reduction of over frequencies due to the imbalance between mechanical power and electrical power, according to Equation (1), making the conventional generators do not operate outside of normal system frequency range. On the contrary, active power is injected by the BESS to the transmission network to avoid low values in system frequency when the short circuit is cleared. Therefore, BESS P-f control reduces system frequency deviations and consequently, it is reduced the disconnection of wind farms by over frequencies and load shedding due to under frequencies.

For this reason, BESS controls of P-f and Q-V bring on a greater integration of wind power into power system in a safe way and with a more quality of service.

To sum up, BESS can be an essential element for a maximum integration of renewable energy sources into the power system due to their capabilities. Furthermore, BESS could help to fulfil the grid codes in cases of high integration of renewable sources into isolated power systems.

Expanding this study with other configurations of BESS as it can be more units, greater capacity, location selection, among others, could consolidate the increase of renewable energies for this type of isolated power systems not so robust in voltage and frequency, being able to fulfil thus, the criteria of the TSO that it imposes to the electrical system.

Acknowledgement

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References

[1] Sistema eléctrico canario. Available online: http://www.ree.es/es/actividades/sistema-electrico-canario (accessed 14 July 2018). (In Spanish)

[2] 2020 climate & energy package. Available online: https://ec.europa.eu/clima/policies/strategies/2020_en (accessed 10 January 2019).

[3] El proyecto ENERMAC potencia la independencia energética y maximización de las renovables. Available online: http://www.itccanarias.org/web/prensa/noticias/np_reunion_lanzamiento_proyecto_ENERMAC.jsp?lang=es (accessed 10 January 2019). (In Spanish)

[4] Mejías-García, L. Mejora de la integración de energías renovables en un sistema insular mediante la incorporación de baterías. Caso de la red eléctrica Lanzarote-Fuerteventura. Master thesis, University of Las Palmas de Gran Canaria, 2018. URI: http://hdl.handle.net/10553/41962

[5] Proyecto ENERMAC. Available online: https://www.proyectoenermac.com/es/ (accessed 10 January 2019). (In Spanish)

[6] Energy Storage for Commercial Renewable Integration. Available online: https://arena.gov.au/projects/energy-storage-for-commercial-renewable-integration/ (accessed 10 January 2019)

[7] Innovative Battery Storage Facility at SCE's Mira Loma Substation Allows for More Renewables. Available online: https://energized.edison.com/stories/innovative-battery-storage-facility-at-sces-mira-loma-substation-allows-for-more-renewables (accessed 10 January 2019)

[8] R&D+i projects that contribute to the business. Available online:https://www.ree.es/en/sustainability/noteworthy-projects/rdi-projects-that-contribute-to-the-business/almacena-project (accessed 10 January 2019)

[9] La Graciosa, the intelligent energy island. Available online: https://www.endesa.com/en/projects/a201701-la-graciosa-the-intelligent-energy-island.html (accessed 10 January 2019)

[10] Subdirección General de Ingeniería, Proyectos e I + D. Endesa Generación, S.A. Proyecto store. 2014.

[11] Medina-Domínguez, E.J. and Medina-Padrón, J.F. Critical clearing time and wind power in small isolated power systems considering inertia emulation. Energies, 8(11): 12669–12684, nov 2015. DOI: 10.3390/en81112334

[12] Pourbeik, P. and Petter, J. K. Modeling and validation of battery energy storage systems using simple generic models for power system stability studies. Cigre Science & Engineering, (9), 2017.

[13] Pourbeik, P. Model User Guide for Generic Renewable Energy System Models. Electric Power Research Institute (EPRI), Inc, 2015.

[14] PowerWorld. Available online: https://www.powerworld.com/ (accesed 27 May 2019)

[15] Criterios Generales de Protección de Los Sistemas Eléctricos Insulares y Extrapeninsulares. Available online: http://www.ree.es/sites/default/files/downloadable/criterios_proteccion_sistema_2005_v2.pdf (accessed on 14 July 2018). (In Spanish)