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The Islands of Cape Verde as a Reference System for 100 % Renewable Deployment

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Abstract*—Fully renewable, isolated power systems have gained relevance given the global agenda related to the energy transition. Thus raising the amount and diversity of the performed grid-related research. However, the existing generic reference systems are usually aimed to a particular type of study and don't capture the influence of technologies and methods used to accommodate renewables such as power electronics, energy storage, demand response, etc. In addition, the majority of studies are focused on the micro-grid perspective. When analyzing grids, size does matter, and yet, there is no benchmark available suitable for validating both static and dynamic studies in the dozens to hundreds of MW range. Therefore, there is a need for a reference system capturing the behaviour of modern, mid & large size isolated power systems ranging from 20 to 100 % renewable energy penetration, accommodating a very diverse technological mix. The purpose of this work is to fill these gaps, presenting a benchmark suitable for studies in mid to large size power system using real data from existing isolated grids. The network of two islands from Cape Verde is used as inspiration for the models due to the relevance of their layout and configuration, but also the country's renewable penetration targets. All the data has been provided by Electra and Cabeólica, the local System Operator and largest renewable utility of the country respectively. The data is Open-Access, accessible in an online repository [1], conveniently prepared and presented in different tables and files covering a range of traditional and modern studies such as: power flow, energy management, control, stability, reliability, resiliency etc.

***Index Terms*—reference power system; isolated power system, minigrid, benchmark power system**

I. Introduction

Motivated by a number of environmental, social and economical reasons, nations worldwide target a transition towards 100 % Renewable Energy Sources (RES) over the course of this century [2]. This of course possesses a number of well-known challenges to any power system related to power flow, quality, balance and stability [3]. Which add up to other traditional ones like weather-related events, catastrophic man-made incidents, etc. Thus, rising the complexity of the necessary power system studies ensuring operational safety.

There are mainly two directions for research focused on reaching higher rates of RES penetration: integration and microgrids. The first focuses on increasing the penetration rates of RES in modern power systems, by for example providing grid support services [4]. On the other hand, microgrid research focuses on small (in size and power) installations that may or not be connected with an external grid and/or couple electricity with other sectors like heat, gas or transport [5]. They usually act as testing field for different developments or aim to power isolated areas lacking access to the main grid. These two research paths feedback one another since they have a goal in common; achieving fully renewable power systems. Microgrids represent an excellent starting point for such research, however at a certain point it is necessary to avoid inclusion of an external grid that balances out the system under study. This could relate to the so-called isolated microgrids initially, but their size is usually limited in the kW range. Such case is gaining relevance as an increasing number of countries target to complete transition to RES for electrical production in the next two decades. Therefore, there is a recent third research direction aiming to study fully renewable power systems. Furthermore justifying the clear need for the definition of new benchmarks characterising Isolated Power Systems.

The proposed reference system represents two different islands belonging to the power grid of Cape Verde, whose installed power are in the dozens and hundreds of MWs range respectively. This allows to capture a number of different grid's dynamics and behaviour. The dataset provides a simplified topological description, load and RES generation profiles with hourly resolution for a whole year. Additionally, information related to the type of electrical machines, cables, energy storage, controllable and uncontrollable loads, failure rates, down-times, are also included. This complete set of data allows for an almost unlimited number of studies from traditional load flow, to different control architectures, stability, power quality, reliability, economic dispatch, etc. The aim is to provide researchers in a multitude of fields with a real system's data that is clearly structured and with an certain origin. Thus increasing both the relevance and replicability of the analysis.

The paper is structured as follows: Section II reviews existing benchmark and reference systems outlining their deficiencies, and the gap filled by this work. Then, Section III presents some generalities about the Cape Verdean system and justifies the relevance of São Vicente & Santiago's networks. While Section IV introduces the Open-Access repository where the datasets are stored. Subsequently, the necessary data for power flow and dynamic analysis is presented in Sections V and VI respectively. Furthermore, the reliability related data is presented in Section VII. While resilience analysis are covered in Section VIII.Lastly, a summary of proposed studies is presented in Section IX which also concludes the paper.

II. A Reference System of Isolated Grids

Current scientific literature tends to define isolated systems as those belonging to islands, rural or remote areas; usually corresponding to a small size (kW range) [5]. Thus, causing that the available studies of systems with 100 % RES penetration focus almost solely on microgrids, either isolated [6] or connected to an external grid [7]. In the case of connected-microgrids the external grid is modelled as a black-box that satisfies any balancing need that might arise from the system understudy. This approach is sometimes even used when modelling networks the size of countries (GW range) justified by international connections [8]. However, different studies covering the influence of volatile generation inclusion conclude that international connections lose relevance as balancing agents as all the countries move forward with the transition [9]. In fact, from the smallest of the micro-grids to the largest cross-border continental network every Power System is isolated [10]. Therefore, there is a clear need for studying the behaviour of 100 % RES-based power systems avoiding the use of concepts such as an "external grid" that takes care of balancing the system, as this defeats the purpose of most studies. Lastly, it is also worth mentioning how studying a 100 % RES-based power system implies the inclusion of new technologies and methods such as power-electronic based technologies, energy storage, demand response, sector coupling, etc. Ultimately, showing the need for a relevant multi-purpose benchmark for isolated power systems capable of capturing mid & large size power systems ranging from 20 to 100 % renewable energy penetration, accommodating a very diverse technological mix.

Examples of available benchmarks and reference systems widely used in scientific literature are: the 2-area 4-machine [11], 6-bus [12], 9-bus system [13], the WSCC system [14], IEEE 14-bus [15], IEEE 33-bus [16], the 68-bus [17], and the IEEE 69-bus [18]. Despite their popularity, they present limitations, specially when considering RES penetration rates above 20 %, power-electronic interfaced technologies, or sector coupling. More specifically, the 2-area 4-machine system doesn't represent a realistic layout as it was developed for small signal stability studies. Both the 6 & 9-bus are too small to to handle different scenarios and technological mixes while 14-bus and 33-bus present insufficient information for certain studies. Similarly, the data provided by the 68-bus system is insufficient for most of modern power system studies; resulting in an outdated and excessive high level benchmark. In fact, even though it would be possible for the individual researcher to use the 14, 33 or 68-bus systems as baseline add parameters and considerations on top of it, that requires time and information that it is generally not easy to find. Particularly, the 69-bus represents a distribution network including and external grid bus as balancing agent. Resulting in a design closer to the connected-microgrid environment than to a large power system. Then, the system proposed in [19] is suitable for frequency response and dynamic studies, but its reduced number of nodes, limits its usability in most static analyses. Furthermore, it should also be mentioned that none of the above included data necessary to perform reliability studies. Then, in [20], a system interconnecting 4 micro-grids with an external grid was proposed. It addressed some of the limitations of the previous standards by presenting sufficient data to conduct static, dynamic, reliability, and resiliency studies, however, it combined four of the previously mentioned benchmarks [12], [15], [16], [18] thus it is again based on imaginary systems. Additionally, it continues with the idea of working with micro-grids thus it is contextualised at distribution level.

To overcome the aforementioned limitations, a benchmark for isolated systems must be able to capture the transition from low rates of RE generation to full deployment. It should also consider the inclusion of new technologies such as storage systems or demand response. In addition, it should be weak enough as to represent a realistic challenge, but remain stable under steady-state conditions. Lastly, its voltage should range from 0,95 to 1,05 pu as these are the usual limits stated in grid codes. Then, regarding provided data, the benchmark should include transmission limitations in order to observe congestion, potential contingencies, etc. It should also include certain topological flexibility in the form of switches that allow to modify the meshed/radial structure in a realistic manner.

Hence, the present paper proposes a reference system suitable for all kinds of static and dynamic studies to be conducted during the energy transition. The benchmark consists on two different isolated systems, in this way, both small and large systems are characterised. They are based on the islands of São Vicente & Santiago in Cape Verde. In fact, the vast majority of the data has been supplied by Electra, the local System Operator (SO) and Cabeólica, the largest renewable utility of the country.

III. The Grid of Cape Verde

Cape Verde is a country located in the Atlantic Ocean, lying approximately at 600 km from the westernmost point of continental Africa. The archipelago is compound by 10 islands (9 inhabited), this reference system focuses on two of them: Santiago and São Vicente. Due to the distance between the islands and the depth of the waters surrounding them, it is not economically feasible for the moment to interconnect them. Thus there are 9 independent power systems, 8 of which are operated by Electra, the local utility company. Only the island of Boa Vista is operated by AEB (Aguas Energías de BoaVista). In addition, and due to their extreme external energy dependency (since they are fundamentally powered with petroleum derivatives), the local government has established the goal of reaching 50 and 100 % RES by 2030 and 2050 respectively. Despite of this, it seems like the international research community has not paid much attention unlike to the systems in Canary Islands and Madeira. [21], [22]

Briefly, Santiago holds the capital of the country, Praia, representing the biggest island of the archipelago in size, population and installed power, but also presents the highest rates of industrialisation. Thus, studies conducted on its model hold the potential of been scalable to large power system scale (e.g. European, North-American, etc.). On the other hand, even though São Vicente represents a mid-size island in the archipelago, it is still large for the microgrid standard. Thus minding the gap between traditional microgrid and a system like the one from Santiago. Lastly, in the real system, these islands are not connected, however, for research purposes their interconnection can be considered for the sake of studies, as for example it allows the modelling of HVDC connections between areas.

Conceptually, this benchmark is designed as a simplification of the transmission network present in the island as of 2020. This implies that most generation units are synchronous machines powered by either diesel or heavy fuel. In fact, although there are currently no hydro installations in the archipelago, their inclusion is considered given the existence of positive feasibility studies pointing towards pumped storage as a possible addition to be undertaken in the near future [23]. Nevertheless, the dataset includes the current system configuration as the base case along with additional units. In this way, the available data can be easily used to define any scenario from 0 to 100 % RES penetration rate, sector coupling, energy storage systems, etc. Clearly, the focus of this work is to provide a flexible system, easy to use and modify.

Figures 1 and 2 present the Single Line Diagrams (SLD) of each island. Note that this schematics correspond to a simplified version of the current state of the transmission grid. Also, note how there are several switches present in both systems noted as blue marks in the diagram. These allow to operate the grid in either radial (default) or meshed approaches and to avoid local blackouts during emergency events. Also, in the figures, white triangles represent a connection point between areas, this was done to avoid confusion with overlapping lines.

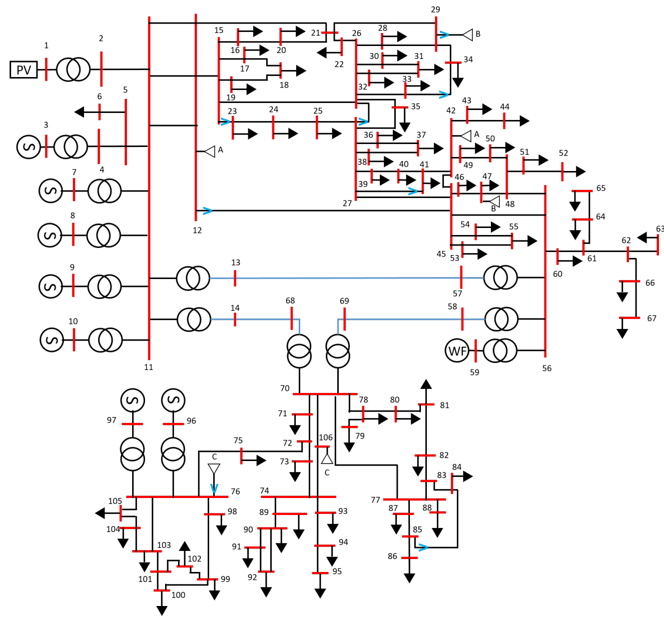

Fig. 1: SLD of Santiago Island's Network.

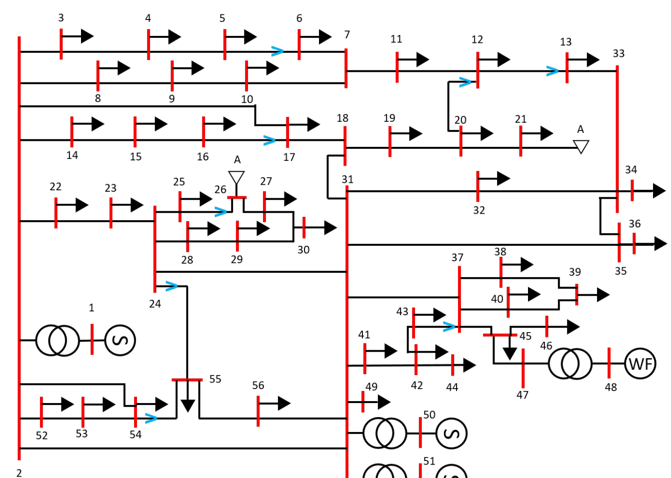

Fig. 2: SLD of São Vicente Island's Network.

IV. Data Repository

As aforementioned, the dataset is Open-Access and available in an online repository [1]. There, any interested party can find a set of conveniently prepared tables and files characterising the transmission network of Cape Verde's islands. The datasets cover currently a range of traditional and modern studies such as: power flow, energy management, control, stability, reliability, and resiliency. However, there is a limit to what we could imagine researchers would require in their investigation. Thus, the datasets are expected to undergo several expansions as more people use them. In fact, we will do our best to satisfy any request regarding missing information sent by our fellow colleagues.

Briefly, the core of dataset are a number of excel files (e.g. SantiagoData) containing a number of different sheets (e.g. Line Data) that divide the information into different categories. Given the current size of the datasets portraying the islands of Santiago and São Vicente and the unusefulness of doing so, it was unpractical to show them in this paper. Therefore, in the following sections the contents of the dataset are described along with certain considerations regarding the how to use the information.

V. Data for Load Flow Analysis

Traditionally, load flow is considered as the most important analysis performed when studying any power system. Basically, it uses data related to the different lines and buses of the network in order to calculate voltage levels. In addition, state estimation studies, which have lately gained relevance due to Smart Grid applications, are performed using roughly the same data. [24]

The excel sheets presenting data relevant for load flow studies are:

- **Line Data:** presents the line ID, origin and destination, type of conductor, number of parallel lines, length [km], resistance [Ω], and reactance [Ω].
- **Conductors:** presents the type ID of the considered conductors, main conducting material, crossed-section [mm^2], Voltage rating [kV], resistance [Ω/km], reactance [Ω/km], capacitance [nF/km], nominal current rating [kA], short-circuit current rating (SCCR) [kA], type of installation as Over-Head Line (OHL) and Underground Cable (UG). It is also worth mentioning how there are two sets of overloading coefficients, according to CIGRE recommendations these should be of 115 and 120 % respectively for long-time (24 h) and short-time (15 min) horizons [25]. However, Electra is forced to use lower values due to the age of the equipment, the general long distance of the lines that would unavoidably cause voltage drops, and the generally elevated temperature of the country.
- **Transformers:** presents type ID, size [MVA], voltage rating [kV], positive and zero sequence of resistance and reactance in per-unit (p.u.), and X/R [%]. The p.u. values mentioned in these tables correspond to he information shown in the equipment's nameplate rating. The connection of all the transformers is considered as Dyn-11.
- **Load Data:** presents the total active and reactive load along with the % of controllable (aiming to demand response) and critical demand (must be satisfied).
- **Weekly Load Profile:** Shows the percentage of peak load for each week of the year.
- **Daily Load Profile:** Shows the percentage of peak load for each day of the week.
- **Hourly Load Profile:** presents the hourly load data based on the season of the year and day.
- **Traditional Generators:** presents the type of generation unit, governor, Apparent Power [MVA], minimum running rates, Q limitations and R/X of the original synchronous generators for each island. Note that DG stands for Diesel Generator while H does so for Hydro.
- **Renewable Generators:** presents the installed Solar Photovoltaic (PV) and Wind (Wx) capacity in a similar manner. Note that the x in Wx can be N, S, E or W; thus representing the cardinal direction of a compass. This accounts not only for differences in wind direction, but also natural shadowing caused by the island's orography. It also mimics the fact that spatially distributed wind farms rarely coincide in their productions rates, usually distributing around 30 to 50 % of their nominal capacity.
- **Hourly Solar Profile:** presents hourly power availability from Solar. Since solar irradiation is more or less homogeneous over relatively large distances in the same latitudes, no distinction is applied.
- **Hourly Wind Profile:** presents hourly power availability from Wind. Note that the WFs present again a cardinal direction index (N, S, E, W) corresponding with the code presented in Table *Renewable Generators*. Thus, those indexes allow to present more realistic scenarios regarding different production profiles for the different Wind Farms (WF) in the system.
- **Storage:** present the type, capacity [MWh], power [MW], charging and discharging efficiencies, but also the initial, minimum, and maximum State of Charge (SOC); all of them expressed in [%].

This is a basic summary of what it is available. However, a few considerations must be stated. For starters, more information about the considered cables and transformers can be found in manufacturer's data-sheet such as [26–28]. Also, some of the node's IDs from the sheets *Traditional Generators* and *Renewable Generators* are the same, this is meant to allow for progressive substitution of traditional units with RES. Then, the tables whose name ends in *Profile* are used by multiplying the relevant weights [%] with the total installed power presented in either *Load Data* or *Renewable Generators*.

Whereas there are currently no Energy Storage Systems (ESS) installed in the islands of Cape Verde, there are plans considering their inclusion. That is, a 1 MW/MWh Lithium-Ion Battery in the island of Sal and another one in São Vicente. In addition, there is an ongoing study exploring the inclusion of pumped hydro in the island of Santiago. Therefore, it is very important for the reference system to incorporate different storage technologies, due to their relevance. That section will be updated in the future as more information becomes available.

In summary, the total possible load of the system is in the dozen and hundreds of MVA range respectively, which includes controlable and critical loads. The dataset provides a simple method to generate hourly profiles for a year. On the other hand, by default the RES penetration is around 20 % divided PV and wind. However, the dataset provides information to formulate scenarios until 100 % RES. Although, it should be stated that, users can decide to include more or less RES and/or traditional units depending on their studies.

A. Annual Hourly Profiles

Regarding the different time profiles. The values related to demand have been build using directly data provided by Electra. Whereas, for the RES a simple yet effective method was applied.

In [29] and [30] are available global datasets regarding solar and wind resources respectively. Both sites allow the user to download for free simple datasets, which can then be used to create annual hourly profiles.

Basically, both sites offer a value representing the monthly mean of resource availability and the average hourly profiles for each month. The metrics are Global Horizontal Irradiance and wind speed coefficient respectively for solar and wind resources. Then, by simple linear interpolation it is possible to deconstruct the monthly averages into weekly averages. Subsequently, the profile is obtained by multiplying the average hourly value for each month times the weekly mean. This produces a grid of 24 $hours/day$ times 52 $weeks/year$ corresponding to 1248 values that correspond to the annual hourly profiles. This values can then be scaled between 0 and 100 to obtain the power availability of a renewable plant in the system as % of its installed power.

Whereas the presented method does not necessarily yield meaningful physical values (specially for wind resource), it does it in statistical terms since it allows to get a clear picture of the resource availability and how it spreads throughout the year. The results fit quite well with the expected results. For example, typical values for the full load hours are 30 to 40 % for onshore and from 40 to 50 % for offshore wind farms while 15 to 25 % for solar farms [31]. Using the site of existing WF and SF, the results where 47 and 21 % respectively. Which is very consistent given the fact that Cape Verde is an island, thus making the division between on/off-shore quite blurry.

Lastly, it is also worth mentioning that if a higher resolution than hourly is needed, then techniques described in [32], [33] can be used.

VI. Data for Dynamic Simulation Studies

Any study aiming to explore the behaviour of a power system in the time domain can be defined as a Dynamic Simulation Study. These are usually divided in Stability and Transient modes; which are traditionally used for System Stability and Equipment Stress studies. Such models avoid certain simplifying assumptions applied in steady state analysis; Which causes their execution times grow exponentially. In practice, the usual time duration of such studies is limited to spawns from micro-seconds to seconds. [34]

The excel sheets presenting data relevant for dynamic studies are:

- **Load Data Reduced:** it presents the same data as *Load Data*, but aggregating certain loads. This is done in order to reduce the computational burden of the simulations.
- **Traditional Generators:** presents a number of parameters regarding the Governor, Automatic Voltage Regulator (AVR), and Excitation types of the machines. In general, the dataset includes the necessary parameters to replicate the generic models presented in [13] and the real one if available.
- **Synchronous Generators:** presents a number of parameters in pu for the machines included in the system, and generic range values if it was necessary to define additional machines. The parameters are: Synchronous reactance, transient reactance, sub-transient reactance (normal and saturated), transient OC time constant, sub-transient OC time constant, stator resistance and stator leakage reactance.
- **Asynchronous Generators:** presents ranges of generic values [pu] used in the definition of additional induction machines. The parameters are: Stator resistance, stator leakage inductance, magnetizing inductance, rotor resistance referred to the stator, and rotor leakage inductance referred to the stator.
- **Wind Turbines:** Presents generic parameters about the wind turbines installed in the islands. The paremeters are: Nominal Power & Voltage, number of poles, Ia/In, R/X and class.

Also, note that transformer's zero-sequence data is presented in *Transformers*, while in the case of the conductors, the zero-sequence can be approximated as three times the positive-sequence [35]. Then, the modeling of each governor, AVR, and excitation systems is not an easy task provided the existence of many different types and the limited data available from the manufacturers, which are reluctant to provide the equivalent transfer functions and their parameters. The objective is to use provide the data necessary to replicate exact models for the devices present in the system. However, in some cases this is not possible for now. As aforementioned, the dataset is undergoing continuous development, we are doing our best to compile all the information. All these datasets can be used to explore how different contingencies, topological changes, sudden generation or load changes affect the behaviour of the system; resulting critical in any stability study, short-circuit analysis or protection design.

VII. Data for Reliability Analysis

The reliability of a power system is evaluated by using a number of different metrics such as: System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability (Unavailability) Index (ASAI/ASUI), Expected Energy Not Supplied (EENS), Average Energy Not Supplied (AENS), and Average Customer Curtailment Index (ACCI). In addition, some other metrics more relevant in isolated systems with large rates of renewable energy like Island Expected Energy Deficiency (IEED) or Island Average Load Shedding Duration (IALSD) can also be easily obtained. A formal description of such indexes can be found in [36–38]. The excel sheets presenting data relevant for reliability studies are:

- **Customers:** presents the amount per bus of normal and critical customers and Distribution Transformers (DT) that feed them. It is assumed that, critical transformers feed exclusively critical consumers and vice versa.
- **Failures:** presents the Failure Rate (FR) $[failures/year]$ and Failure Duration (FD) $[hour]$ of each line. FR is computed using the Failure Rate Index $[failures/(year* km)]$ and the length line from the *Conductors* sheet. For the transformers an FR of 0,25 $failures/year$ is assumed. Regarding FR, they were obtained as trade-of between talks with the SO and scientific literature.
- **Substation Reliability:** presents the FR and FD for different elements like Circuit Breaker (CB), DT and busbars.
- **Outage Scenarios:** presents a number of predefined outage scenarios, distributed throughout the year, that

can be used as starting point for reliability or dynamic studies. This is relevant not only for studying how the inclusion of higher rates of RES potentially affect the grid's reliability with metrics like the SAIDI or SAIFI; but also in stability studies, faults, etc. The data presented is: Time of the year (given as week [W], day [D] and hour [H]), outaged element, affected buses, load [kW], number of customers and duration [$hour$] until the full restoration of the outaged element.

VIII. Data for Resiliency Analysis

Power system resilience is defined as the ability of a power system to withstand a particular disrupting event, and then respond proactively in order to restore pre-event operation. Said disrupting events can be related to natural phenomena (e.g. storms, hurricanes, earthquakes, tsunamis, etc.), component ageing, and/or man-made incidents (e.g. maintenance or operation errors, terrorism, etc.).

Briefly, Figure 3 presents the typical resilience curve over time of a network sustaining a contingency, where the Resiliance Level (RL) is considered 1 during normal operation and 0 during a full-blackout. In the same figure, t_0 to t_5 stand respectively for the time in which the event starts, the minimum resilience point is reached, restoration starts, restoration ends, full service recovery starts and full recovery is achieved. There is no consensus yet in how to formally aboard this topic, thus, an extreme event scenario is defined in this section as suggested in [39].

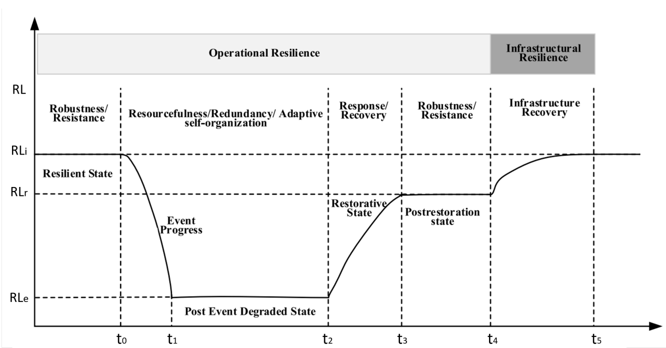

Fig. 3: Typical Resilience Curve of any System. [40]

In the case of Santiago Island, the extreme event is initially caused by severe storm. In week 23, day 2 at 23:00 a lightning strike causes the connections between bus 70 and buses 68 and 69 to disconnect; isolating the bottom part of the SLD (Figure 1). Even though generators connected at buses 96 and 97 do not trip, their size is not enough to power the whole network. Thus, load shedding schemes are activated in order to protect the system from a total blackout shortly after the trip. Subsequently, at 04:00 connection is restored between bus 70 and bus 69, allowing a partial re-powering of the system. Lastly, at 13:00, bus 70 is fully operational. This allows to re-power the remaining shed loads, reaching full resilience at 15:00 of the following day.

On the other hand, in São Vicente island, the generator at bus 1 and the WF at bus 48 are the only ones powering the grid as the remaining generators at buses 51 and 50 undergo maintenance and stay as backup respectively. Then, due to an unnecessary trip at 09:00 in week 29, day 7 at 10:00, the transformer between buses 1 and 2 gets out of service, effectively disconnecting the generator. Since the WF is the only remaining generator in the system, load shedding schemes avoid complete blackout. At 15:00 generator at bus 50 starts ramping up its production, reaching nominal production at 17:00; which allows to recover part of the shed loads. At 20:00 the breaker at bus 2 is fixed, allowing for the connection and start-up of generator at bus 1. Finally, the system is considered restored at 21:00.

This hypothetical chains of events presented above can be used to estimate the resiliency of the system as well as to test different restoration strategies and control schemes or, for example, what would be the role of an energy storage system or demand response in such contingency.

IX. Conclusions

This paper presented a reference for mid-large power systems aimed to support research in the transition to 100 % Renewable penetration rate. The benchmark was designed in collaboration with Electra and Cabeólica, respectively the SO and largest renewable utility of the country. Thus increasing both the relevance and replicability of the analysis conducted using this reference system.

First, a comprehensive review of current available power system benchmarks was presented. There, the need for an isolated reference system was justified. Then, Cape Verde's case relevance was presented along with the simplified network of two of its islands: São Vicente & Santiago. Which range from the dozens to the hundreds of MW, thus minding the gap from microgrids to country-size power systems. Subsequently, the Open-Access dataset was made available in [1]. The provided information can be used in a nearly unlimited number of studies; a summary of them is presented as an example in Table I. Therefore, researchers can use this reference system in order to develop solutions for the energy transition's challenges in a accurate and very time-efficient manner. Lastly, we would like to remind that the dataset's development is ongoing, thus suggestions, and applications for additional data are not only welcome, but encouraged.

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TABLE I: Summary of Suggested Studies.

Topic	Potential Studies
Topology Planning	• Grid expansion • Radial vs Meshed operation • Grid reinforcement
Power Flow Analysis	• Optimal Power Flow • Isolated System Power Flow • Island Interconnection • Black-start • Inverse Current Flow due to RES
Control	• Distributed, robust, data-driven Control • Different Control Architectures • RES-based frequency support • Demand Response strategies • Energy Storage Management
Energy Management	• Dispatch strategies • Unit Commitment • Market Clearance • Uncertainty Effect on Dispatch
Stability	• Inertia constant estimation & evolution • Small signal stability • Impact of RES on system stability • Impacts on topological switching • Short-Circuit Transitory
Reliability	• Reliability Index Evaluation • Contingency Evaluation • Cascading Event Identification • Fault & protection studies
Resiliency	• Extreme Event Definition & Modelling • RES-based Resiliency Dependency • Damage & Losses caused by extreme events

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