

A Survey on Innovative Solutions and Projects for the Integration of Renewable Generation in Weak Power Grids

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Abstract. This paper deals with the most relevant issues about the integration of renewable generation in weak power grids. Initially, the main parameters that characterize these types of networks are reviewed, in terms of short circuit power, system inertia and frequency and voltage characteristics. Afterwards, improvement measures in the structure of weak power grids are proposed, analyzing different storage technologies in order to guarantee a high efficiency and reliability of the power system. Finally, the paper reviews the most prominent projects developed worldwide which include the integration of renewable energy in weak grids.

Key words

Renewable Distributed Generation, Weak Power Grids, Wind Energy, Photovoltaic Generation, Storage Technologies, Hydrogen.

1. Introduction

This paper deals with the issues associated with the integration of renewable generation in weak power grids for two main reasons. First, the number of publications dealing with weak networks is limited in relation with papers studying the integration of renewable generation in strong networks, in which the network problems are few well known. The second reason is related to the characteristics of weak networks, where the generators are subject to greater demands for similar events occurring in strong networks. Additionally, in weak networks, there are additional problems that do not occur in strong networks, so that the study of network events is more comprehensive.

According to [1], a power grid can be considered weak when the source impedance is large, the short-circuit power is low and the mechanical inertia is small. The strength of a system is defined in terms of the amount of generation loss necessary to reduce in 1 Hz the frequency of the system without shedding loads. The strength of a weak network, for which the power flow from neighboring areas is not significant, will depend on the power-frequency characteristic of the connected load. This way, a weak network is one in which the capacity of

the network is small with respect to the loads in the system [2]. Other possible definitions are based on the weakest bus of a power system. A weak point of a network is one where changes in the active or reactive power flows to or from the network cause voltage changes at that point and neighboring points of the network [3]. The weakest bus of a system is the one that is closer to voltage collapse [4].

In turn, there are several ways to measure the strength of a network or identify weak networks in relation to the above definitions, such as the inertia constant, ie, the ability of an AC system to keep the voltage and frequency controlled depends on the rotational inertia of the system. The lowest is the inertia constant, the weaker the system. In networks with renewable generation, inertia constant is usually low, since the connection of such generators to the network is performed by power electronic converters.

Regarding the short-circuit power [5], it must be noted that transmission lines in weak power grids are normally operated at lower voltage levels than strong networks. In addition, power is supplied by few generating groups, with small unit power. Therefore, weak grids show low short-circuit power values. In general, the short-circuit power at a given Point of Common Coupling (PCC) is higher when the grid is meshed nearby the PCC. Weak and isolated grids mainly consist of radial feeders, and therefore, their short-circuit power values are still lower.

When integrating renewable generation in one location, one must consider the source impedance before and after connecting the generation to the grid, or the short circuit power available at the connection point [6]. This is usually measured using the Short Circuit Ratio (SCR), defined as the relation of the short-circuit power at the PCC to the capacity of the generation plant. SCR values lower than 20 are considered indicative of a weak network [7].

Finally, some authors measure the strength of a grid in terms of the voltage stability of a bus or an area of the grid [8]. Also, the R/X relation in the PCC can give an indication of the grid stiffness, being its value large for

weak grids, because these grids tend to be resistive distribution networks [9].

2. Improvements in the structure of weak power grids.

According to the definition of a weak power grid, the electricity grid of an island, or island network, is the most common case of this kind of network. In order to minimize the technical problems associated with integrating renewable energy in weak grids, it is advisable to reduce the impedance of the equivalent circuit in the PCC of the power plants, selecting locations with "strong" network connection. However, as explained before, this is not always possible in island networks, taking into account that energy resources are often in remote areas. Therefore, the following improvements are proposed [10]:

- 1) Development of interconnections between island grids, as the interconnection proposal between the grid of Gran Canaria Island and the grid of Lanzarote-Fuerteventura islands, in the Canary archipelago in Spain. Depending on the length and rated power, the interconnection can be done using HVDC technology. Upgrade of existing power networks could also be necessary.
- 2) Large scale deployment of energy storage and regulation systems, including pumped hydro where available, which will be introduced in Section 3.
- 3) Repowering of existing generation plants, normally aged wind plants, to take advantage of improvements in technology [11].
- 4) Development of advanced grid codes with stringent voltage and frequency fault ride through requirements [12], so that generation assets based on renewable energy sources actively contribute with reactive and active power control strategies.
- 5) Improved energy efficiency and energy management systems, strongly related to improving capacity forecasting techniques.
- 6) Reduction of electricity generation costs.

3. Energy storage systems

Energy storage systems are a promising solution for integrating renewable generation in weak power grids as it allows increasing the availability of renewable sources in island grids. Also, energy storage allows increasing the efficiency of the electrical system, reducing the need for backup power generation. And it also increases the reliability of the system, avoiding the costs of supply disruption. Moreover, storage technologies are important for leveling the load curve reducing the difference between peak and valley hours.

Fig.1 shows different applications of energy storage technologies. In terms of its application in electric power systems, two types of storage can be considered [13]:

- 1) Electricity/Electricity: batteries, flywheels, hydro and compressed air
- 2) Electricity/Fuel: hydrogen storage

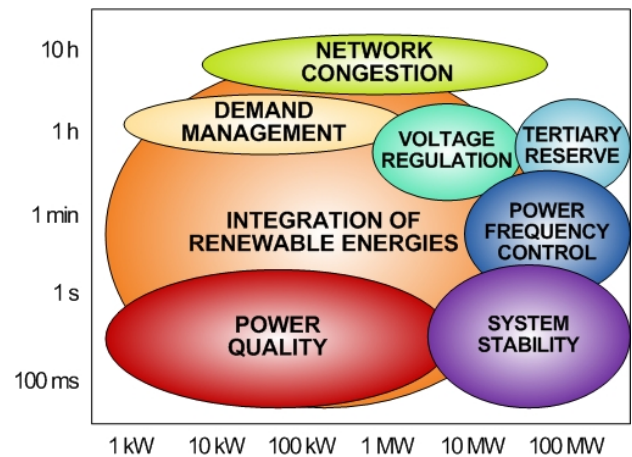


Fig. 1 Applications of storage systems

A) Hydro storage

Hydro storage systems consisting on turbine/pump units are a good solution to integrate variable generation in weak power grids in islands with proper orography. An example of this is the wind-hydro-pumped station of El Hierro, in the Canary Islands, that integrates an 11.5 MW wind power plant with a hydro storage plant with 11.32 MW of turbine capacity and 6 MW of pumping capacity.

B) Batteries

An example of using batteries to integrate renewable energy is Project Store launched by Endesa in the Canary Islands. With a budget of over 14 million euros, financed by European funds, Store Project allows storage of energy in batteries 4 feet high by 8 wide, which serve as energy reservoir available for possible eventualities, and also allow storing surplus energy, as in times of high wind. The medium term objective is to replace all existing backup gensets on the archipelago of the Canary Islands, as well as to improve the economy and security of supply and to achieve greater integration of renewable energy [13].

C) Flywheels

The main advantages of flywheels against batteries are very high efficiency (the reduction of variable cost, mainly losses, produces considerable savings in facilities working 24 hours a day), long lifetime (about three times the lifetime of batteries) and reduced time to load (flywheels are fully loaded in 4 minutes unlike batteries that need several hours to load).

REE, the spanish system operator, has installed a flywheel in Lanzarote Island connected to a 66 kV substation that can supply 18 MWs instantaneously to respond to sudden frequency drops due to the loss of a diesel generator, arresting the frequency variation and avoiding the trip of renewable generation plants and load shedding.

D) Hydrogen storage

In [13] it is proposed to combine wind energy with storage systems based on H₂. This system would absorb untapped wind power in valley hours as well as operating as a load to smooth the daily load curve. Possible locations of hydrogen storage systems on islands would be onshore and offshore wind farms or distribution substations. This alternative can be seen in Fig.2

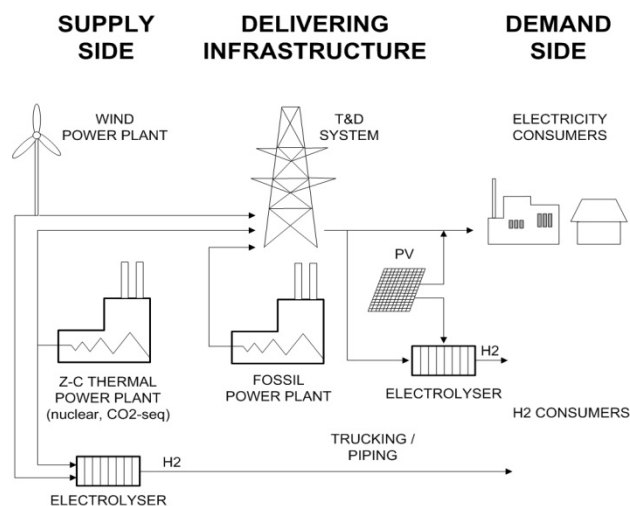


Fig. 2 H₂ storage system application [14]

4. Comparison of characteristics of storage technologies

The use of storage technologies can facilitate the connection of microgenerators to the network, allowing to smooth the production from intermittent energy sources. Flywheels, batteries, supercapacitors, fuel cells, etc, are the devices developed at the moment to store energy [15]. The main characteristics of these storage devices are shown in Table I [16].

TABLE I. Technical characteristics of energy storage systems

	Efficiency (%)	Capacity (MW)	Energy density (Wh/kg)	Capital (\$/kW)	Capital (\$/kWh)	Response time	Lifetime (years)	Maturity	Environmental impact
TES	30-60	0-300	80-250	200-300	3-50	-	5-40	Developed	Small
PHS	75-85	100-5000	0.5-1.5	600-2000	5-100	Fast (ms)	40-60	Mature	Negative
CAES	50-89	3-400	30-60	400-2000	2-100	Fast	20-60	Developed	Negative
Flywheel	93-95	0.25	10-30	350	5000	Very fast (<ms)	~ 15	Demonstration	Almost
Pb-acid battery	70-90	0-40	30-50	300	400	Fast	5-15	Mature	Negative
Ni-Cd battery	60-65	0-40	50-75	500-1500	800-1500	Fast	10-20	Commercial	Negative
Na-S battery	80-90	0.05-8	150-240	1000-	300-500	Fast	10-15	Commercial	Negative
Li-ion battery	85-90	0.1	75-200	3000	2500	Fast	5-15	Demonstration	Negative
Fuel cells	20-50	0-50	800-10000	4000	10-20	Goog (< 1s)	5-15	Developing	Small
Flow battery	75-85	0.3-15	10-50	600-1500	150-1000	Very fast	5-15	Developing	Negative
Capacitors	60-65	0.05	0.05-5	400	1000	Very fast	~5	Developed	Small
Supercapacitors	90-95	0.3	2.5-15	300	2000	Very fast	20+	Developed	Small
SMES	95-98	0.1-10	0.5-5	300	10000	Very fast	20+	Demonstration	Benign

Besides, in Fig. 3 the applications of storage are represented as a function of discharge duration and energy rating [17].

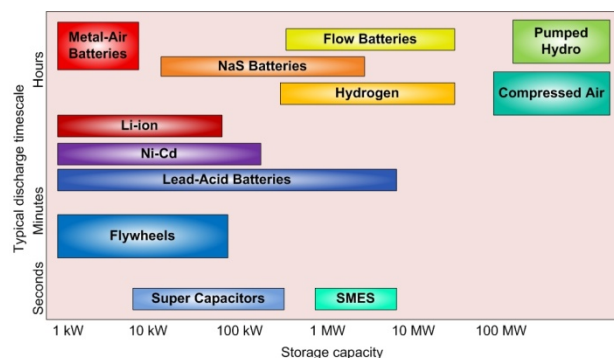


Fig.3 Characteristics of storage [17]

5. Relevant Projects

In this section the results of the search for projects related to the integration of renewable generation in weak power grids are collected. In general, these projects are big European projects with multiple participants and funded by the European Commission within the framework of various research programs.

The projects are presented in chronological order. The main objectives of the projects are described and additional information sources are provided.

The described projects are Dispower, Res Project for El Hierro, Renewislands, Upwind, Stories, Tres, Insular, etc.

A) DISPOWER

The aim of the “Distributed Generation with High Penetration of Renewable Energy Sources” (DISPOWER) project is to help in the transition from the actual centralized system to a market-oriented decentralized system. For this purpose, the project deals with the renewable and distributed generation integration taking into account technical, legal, economic and social factors.

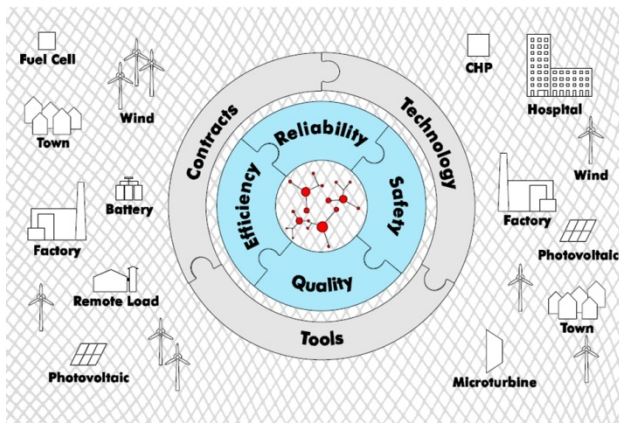


Fig.4 DISPOWER project [18]

The objective of the project is to design the structure of the connection of the distributed generation both to the European synchronous network and to isolated networks. It is expected that important structure changes will be suggested and they should take into account factors such as the network control, the network stability, the quality of supply and the security of supply.

These are the tasks of the project:

- Control concepts and strategies in networks with Distributed Generation.
- Quality and security standards in networks with Distributed Generation.
- Development of planning and design tools to assure the integration of Distributed Generation.
- Information Technology system development for the energy management based on the Internet.
- Research on energy market contracts and prices.

A description of the tasks carried out in the project are given in [18]. Besides, in the project it was analyzed in detail the integration of Distributed Generation in islands and weak grids. In [19] the related tasks are described and a detailed report with results is given in [20].

B) RES project for El Hierro

The name of the project is "Implementation Of 100% Res Project For El Hierro Island Canary Island. 1st phase". The objective of the project is to have an autonomous energy system based in renewable energy in El Hierro island (Canarias). Among the generation systems, a wind power generation system with hydro storage is considered.

The initial commissioning date of the project was 2005. However, the project was delayed and derived in the Gorona del Viento project, that has built the combined wind and hydro power station. The power station is composed of a wind farm, a hydro pump system and a hydro power station. The wind farm supplies power directly to the grid and simultaneously supplies a hydro pump system that stores water in a reservoir. The hydro power station generates power using the storage water, increasing the security of supply and the network stability [21].

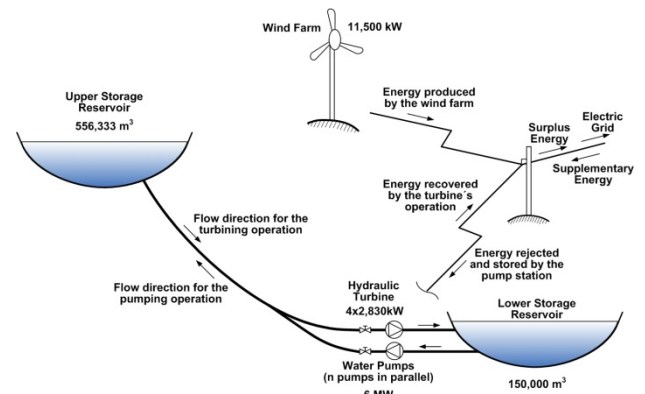


Fig. 5 Combined wind and hydro power station in El Hierro

The combined wind and hydro power station transforms an intermittent power supply into a controlled constant supply, maximizing the wind power utilization. The thermal plant works as a reserve for low wind periods, minimizing the fossil fuel consumption.

The forecasted demand is 48 GWh in 2.015, based on the Canarias energy planning PECAN 2006; however, the design of the water installation, that it is not modular, has been done for 2030. Besides, the capacity of the reservoir takes into account the water needed for public use in the island.

C) RENEWISLANDS

The objective of the "Renewable Energy Solutions for Islands" project is the integration of renewable generation, fuel cells and hydrogen infrastructure in the power network in islands [22].

Some of the objectives of the project are the analysis of the integration of intermittent renewable generation in isolated systems and the development of a generation system based on renewable energy and fuel cells in the Porto Santo island, Madeira. In [23] the first two parts of the project are described and in [24] another two parts. The project is based on model of an isolated network with renewable energy and storage using the software HYDROGEMS. In Fig. 6, the configuration used by the renewable energies to generate hydrogen for the supply of a fuel cell is shown.

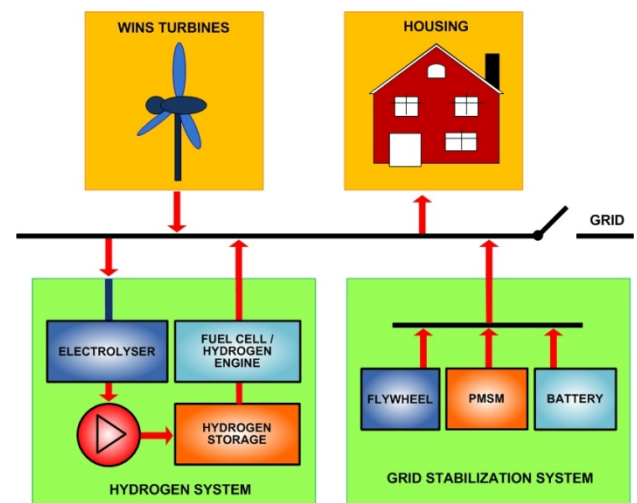


Fig. 6 renewable energies and fuel cell

D) UPWIND

The purpose of the “Very large wind turbines for onshore and offshore applications” project is to analyze the future of the wind energy. More precisely, the design of 8-10 MW wind turbines for offshore and onshore applications is analyzed [25].

Regarding weak grids, they have been analyzed in the task 9 “WP9: Electrical grid”. The design requirements of the wind turbines have been analyzed taking into account the reliability requirements of the power grid, and design improvements have been developed. The part 3 of this task was related to small isolated systems.

The design and the control of the electrical system of the wind farm has been analyzed, with relation to the grid code and the participation of the automatic control of frequency and voltage. The system inertia, the parameters of the protection relays, the voltage and frequency stability, the combined droop and inertia control, etc. have been addressed.

E) IS POWER

The denomination of the project is: “Isolated power systems: knowledge and technology sharing: distributed generation, grid and demand management”. The objective of the IS Power project is the analysis of the sustainable development of the island system economy managing the natural resources and integrating them efficiently in the power grid. The aim is to develop technical and regulatory frameworks to improve the operation of these energy systems and facilitate the integration of renewable energy and distributed generation [26].

The project is divided in four working groups that deal with these subjects:

1. Network management in isolated systems and distributed generation integration methods.
2. Distributed generation technologies: characteristics and impact of the power in isolated systems.
3. Demand side management, procedures and tools, and the impact in isolated systems.
4. Regulatory frameworks to facilitate the integration of distributed generation in isolated systems.

E) STORIES

The denomination of the project is: “Addressing barriers to STORage technologies for increasing the penetration of Intermittent Energy Sources”. The aim of the project is to facilitate the integration of renewable generation in islands by including in the regulatory frameworks the changes needed by the storage technologies. Besides, one of the particular objectives is to analyze the aspects of grid connection and stability when the renewable generation penetration in islands is low [27].

F) TRES

The denomination of the project is: “Transition to a sustainable energy model in Madeira, Azores and Canarias”. The objective of the project is to find technical solutions to maximize the renewable generation in Canarias. The results can be extrapolated to Madeira and Azores. Five particular objectives are defined: develop meteorological models for photovoltaic and wind power forecasting, analysis of the dynamic stability of the grid with renewable generation, identify the feasible storage capacity to compensate the variability and intermittency of the renewable generation, analyze the use of the biomass for the production of biofuels and measures for the energy efficiency [28].

The project is divided in five parts. The second part deals with the dynamic stability of the island grids taking into account the effect of the renewable generation in the grid.

6. Conclusions

This paper has presented the state of development experienced by weak networks, addressing its definition, and improvements that can be introduced into their structure for more efficient operation of the electricity system. Following, we have reviewed some of the proposed solutions with storage technologies to optimize the integration of renewable energy in weak grids. Finally, the most relevant projects carried out or being carried out for the integration of renewable energy in weak grids has been detailed.

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