Electrical Power and Energy Systems 73 (2015) 805–818

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

# Reliability and management of isolated smart-grid with dual mode in remote places: Application in the scope of great energetic needs

Antonio Colmenar-Santos *, Miguel-Ángel Pérez [1], David Borge-Diez [1], Clara Pérez-Molina [1]

*Department of Electrical, Electronic and Control Engineering, UNED, Juan del Rosal, 12, University City, 28040 Madrid, Spain*

ARTICLE INFO

*Article history:*
Received 30 April 2014
Received in revised form 20 May 2015
Accepted 3 June 2015
Available online 23 June 2015

*Keywords:*
Isolated system
Distributed generation
Smart-grid
Prototype
Great power

ABSTRACT

Energy needs increases day by day in those areas of the world where the electrical distribution lines are not available. This situation limits the industrial and economic development of these areas as well as the establishment of the population, so that it facilitates the exodus and the uprooting of people. At the moment the electrical energy supply in remote areas is based on solutions with generator sets, consuming great amounts of fuel with a great environmental damage. The technological development of renewable energies and the new concepts for their management, make possible proposing off-grid generation solutions for providing great amount of energy with high quality and reliability. Along this paper, a smart-grid configuration is proposed which is developed with products of proved reliability and which uses renewable energies as main generation source. This configuration allows having "standard" grid services anywhere, without the need of connection to the traditional grid. Environmental, economic and operation benefits of using these technologies against traditional solutions are also presented in this paper. This proposed solution allows the economical development and exploitation of areas where due to the lack of energy or to the energy cost it has not been possible until now.



## Introduction

The availability of electrical energy in large amounts and high quality is considered as a normal service in developed countries [1,2]. Normally, high energy consuming areas are connected to generation plants which are managed by regulation companies that contribute to the stability and quality of the system. But this situation is not usual in other regions of the world. As a general goal, the availability of electrical energy in less-favoured areas must be one of the actions for their development, as other services, like highways, communications, water and other components which comprise necessary infrastructures for this development [3,4].

To overcome the energetic problem of these areas the first option would be the arrival of a suitable grid. But most of the time this is not possible due to the distance, the orography or the absence of a grid for connection. In short, due to the high cost or the low profit for the distribution companies, this makes it unviable.

An isolated energy generation solution is not only a technical or economic exercise; it must be raised also from a sociopolitical point of view [4]. This type of installations are usually economically supported or promoted by public or private development plans [5]. These plans are elaborated considering the real needs of population.

The existing solutions of diesel generation exhibit an costs elevated of execution, operation and maintenance and a high environmental impact, pollution and noise. Taking advantage of the developments that are appearing, it is time to improve these solutions, reducing the costs of energy and the damages of these diesel solutions.

A technical solution based on renewable generation systems and electrical storage is going to be presented. This system is able to generate a high power electrical grid, from hundreds kilowatts to dozens of megawatts with an electrical energy storage capacity up to gigawatts/hour.

## State-of-the-art

### *Diesel generation as current predominant solution: weaknesses and strengths*

Diesel generators have been the traditional solution to decentralized electrification needs. This is a technology very extended,

* Corresponding author. Tel.: +34 913 987 788, +34 913 986 476; fax: +34 913 986 028.
*E-mail address:* acolmenar@ieec.uned.es (A. Colmenar-Santos).
[1] Tel.: +34 913 986 476; fax +34 913 986 028.

http://dx.doi.org/10.1016/j.ijepes.2015.06.007
0142-0615/

**Acronyms**

| | |
|---|---|
| GNL | Liquefied natural gas |
| VDE | Verband Deutscher Elektrotechniker |
| UL | Underwriters Laboratories |
| PO12.3 | Norm of Spanish Mains, Requisite of answer in front of hollows of tension of the facilities of production of energy of special regime |
| UPS | Uninterrupted to power system |
| SCADA | Supervisory Control And Data Acquisition |
| RJ-45 | Registered Jack 45 |
| TCP | Transmission Control Protocol |
| RTU | Terminal Remote unit |
| SNMP | Simple Network Management Protocol |
| SMS | Short Message Service |

well-known and trustworthy. But these equipments are permanently running and not always following any criterion for the optimization of generation-demand relation. In addition, these systems show several problems that make difficult consider them as a good solution nowadays:

- The main disadvantage is the environmental pollution, in that diesel generators consume fossil fuel that always produces a contamination by $CO_2$ emission. The polluting gases released by a diesel generator is (kg/MW h) [2]:
  $CO_2 \rightarrow 590–800$
  $NO_x \rightarrow 4.5–18,6$
  $SO_2 \rightarrow 0.18–1,36$
  $CO \rightarrow 0.18–4$
- Another problem is the acoustic contamination of these systems that affects people quality of life in the surroundings. The acoustic contamination of a diesel generator is calculated as [6]:
  Level of sonorous pressure to 10 m > 80 dBA
- The lifetime and maintenance of diesel generators is another disadvantage since they are electromechanical systems with elements in movement and a combustion engine. These systems require periodic maintenance that affect to energy availability and suppose an economic cost. Also, diesel generators have a lifetime expressed in running hours, with typical values around 20,000 h which means the complete replacement of the system. In some cases redundant systems are installed to guarantee availability [7].
- With respect to power quality, generator sets are very sensitive to variations of load and in case of strong changes in load value they undergo variations in frequency and voltage values, being able, in some cases, to cause bad operation in connected systems [8].
- Finally, they have the disadvantage of logistics, as a generation system based on a diesel generator has the need of fueling. This problem is greater as the distance to the supply point is bigger.

*Hybridization of energy flows*

In this hybridization form (Fig. 1), energy generation and consumption management and control are made in alternating current (AC Coupling). This method has a bigger complexity [9] with respect to those systems which hybridize energy flows in direct current (DC Coupling) since control systems for energy flows adding must be adapted to voltage values that varies in a sinusoidal way. Control loops must keep a suitable power quality and manage different generators dispatch as a function of the consumptions that must be supported [10].

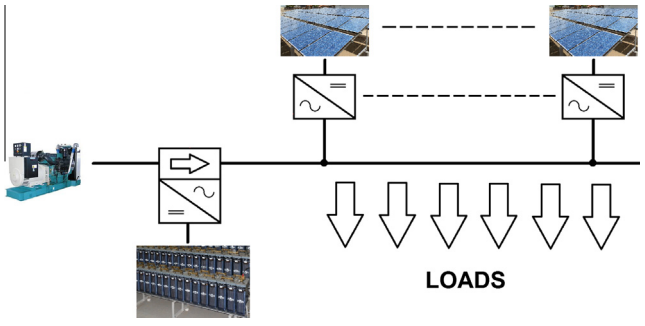


**Fig. 1.** Standard scheme for alternating hybridization (AC Coupling).

In these schemes, in which the consumption profiles and consumption load steps are initially known, the greatest problem is maintaining frequency and voltage of energy supply stable. This function is made in the conventional grid by the grid regulator company, but in an autonomous system must be made by one of the components of the system. It could be easily made when only an inverter provides AC output to grid, so that it generates a stable grid signal with a maximum output power value. But if the system must generate several mega-watts, it is reasonably to use more than one generator (inverter, gen-set, etc.), located in different places, being needed different power source will be necessary: photovoltaic, wind, hydraulic, etc.

*Distributed generation*

Distributed generation is defined [11] as electric generation or storage systems that are located inside or near the consumption points. Distributed generation based on renewable sources can be defined as an energy generation system that has available one or more renewable energy sources, even of different type, energy storage system and also non renewable energy sources, located as closer as possible from loads depending on the availability of the renewable source used [12].

The use of this configuration has technical, economic and environmental advantages and disadvantages that have to be considered [2].

Technical advantages:

- Improvement of electrical energy supply reliability since reduces dependency of energy flows from external lines.
- Assistance in energy demand management at peak times. It can avoid the over-sizing of installed power, as distributed generation plants would be in charge of deal demand changes in local demand.
- Reduction of energy losses both in energy distribution and transport lines. The correct distribution of generation systems reduces the routes of the power flows and consequently power losses, in contrast to other solutions based on great power plants for generation, transport and distribution. In a country as Spain power losses in transport and distribution lines exceed 10% of the generated energy.
- Affects the stability of the system, since it can be used as an energy reserve, making consumption or injection of reactive energy to stabilize voltage, as well as consumption or injection of active energy for the frequency control.
- Allows a modular implementation of generation systems depending on future energy requirements.