ENERGY SUPPLY TO A SMALL ISLAND BY WIND AND HYDRO POWER: DYNAMIC ANALYSIS

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ABSTRACT: "Central Hidroeólica de El Hierro" is a project promoted by local authority Cabildo de El Hierro and the local utility Unelco-Endesa. Performed by the research and development organization Instituto Teconlógico de Canarias, this project is related to build an autonomous power system for El Hierro Island, mostly depending on wind energy but aided by hydro and diesel units.

1 INTRODUCTION

Canary Islands present good wind resources. As a consequence, electric energy production from wind is a continuously growing activity. Although most of this production is a grid-connected one, there are several projects for applications such as stand-alone desalination systems, supplying remote rural areas and self-powered power systems.
"Proyecto Red-Lanzarote" [1] was a Joule Project concerning a wind/hydro/diesel system for water desalination in Lanzarote Island. That project was promoted by the local authority Cabildo de Lanzarote and performed by the research and development organization Instituto Tecnológico de Canarias (ITC). A new project called "Central Hidroeólica de El Hierro" is related to build an autonomous power system, mostly depending on wind energy. This new project is promoted by Cabildo de El Hierro and the local utility Unelco-Endesa and also performed by ITC. In both projects, the required Dynamic Analysis of the projected power system was performed by the Electric Energy Department of the Universidad de Las Palmas G.C. for ITC.
This paper is related to the "Central Hidroeólica de El Hierro" and focused to the dynamic analysis task. El Hierro is one of the smaller one in Canary Islands. With about 7,000 people and nowadays powered by small diesel units, this project proposes to cover the common demand of electric energy making use of renewable sources: electric energy production from wind and store energy by an hydraulic plant and a pumping station. Diesel units will be used for emergency and critical operational states.
Operational states have been selected by ITC as a result of wind and water availability studies and load forecasting. Dynamic analysis was performed on those selected operational states. Dynamic analysis was considered as an opportunity to estimate the operational requirements to be satisfied by the system components planned to install, mainly ranges and procedures of operation.

2 PROPOSED POWER SYSTEM

Figure 1 shows a schematic diagram representing the power system proposed by ITC and Unelco-Endesa. Three types of generation units are present:
Diesel units: That is the present way to satisfy the island demand of electric energy. It is expected that diesel units contribution will decrease in the new proposed power system.
Hydro units: Three hydraulic turbines will be coupled to 3.7 MW synchronous generators. A first pipe will connect an upper tank to a down tank. A second pipe will be used for pumping from the pump station.
Wind generators: 19 wind turbine generators of about 900 kW will compose the planned wind park.

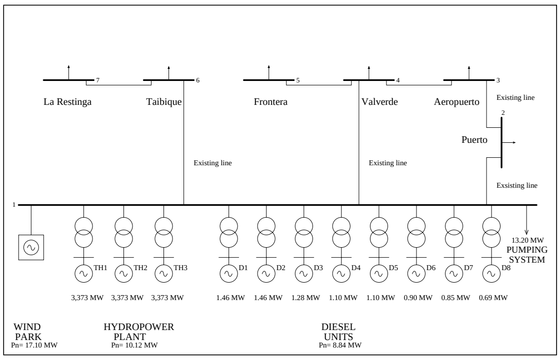

Figure 1: Proposed power system

Total load of the power system will consist of the common island demand and the load from the proposed pumping system. Both loads will be supplied from wind generators, aided by the hydro-turbines or -if needed- by diesel units. Typical models are used in representing all the power system elements [1][2][3], setting input mechanical power to wind generators to a constant fixed value and not allowing appreciable reactive power interchange with the network.
As a first stage in the power system analysis, operational states selected by ITC were classified according to nature of the generation source (Table I).

Table I**:** Operation states classification according to nature of generation

State	Cases	Generation nature
A	1 to 7	Wind+Diesel
B	8 to 17	Wind+Hydraulic

Although all the cases were analysed, by available space in this paper only two cases are presented: case 5 (operational state A) and case 14 (operational state B). Case 5 is related to a wind level penetration of about 60%, whereas case 14 is about 85%.
Initial steady-state analysis was started from the following values, in which obtained slack bus power has been included:

Case 5

Load - common demand	8219 kW
Load - pumping system	8191 kW
Wind generators	9834 kW
Diesel units (slack bus)	6628 kW
Hydro turbines	0

Case 14

Load - common demand	8478 kW
Load - pumping system	1334 kW
Wind generators	6421 kW
Diesel units	0
Hydro turbines (slack bus)	3456 kW

3 DYNAMIC ANALYSIS

The main goal of dynamic analysis was to point out the dynamic properties of a system such as the proposed one, in reference to feasibility. Factors related to the desirable operational behaviour of wind generators were investigated.
Some of the selected disturbances are listed in Table II. Results from simulations listed in Table III are shown in figures 2 to 10.

Table II: Selected disturbances for dynamic analysis

Disturbance		Remarks
3 phase short circuit		100 ms, 250 ms
Load loss	total/partial	Pump load, bus load
Generation outage	total/partial	Hydro, diesel

Table III: Simulations carried out on Cases 5 and 14

State	Study-Case	Disturbance
A	5-a	S.C. (100 ms) Bus 1-20kV
A	5-b	S.C. (250 ms) Bus 1-20kV
A	5-c	Load loss (2.3 MW). Bus 2
A	5-d	Generation loss (1.35 MW). Diesel
B	14-a	S.C. (100 ms) Bus 1-20kV
B	14-b	S.C. (250 ms) Bus 1-20kV
B	14-c	Load loss (0.37 MW). Pump

In reference to figure 2 to 10, some remarks can be made:

Study-case 5-a: 100 ms short circuit. Bus 1, 20 kV (Fig. 2)
It can be observed that initial maximum values of voltages and frequency are slightly higher than usually observed in typical systems:

- Network frequency rises to an initial peak value of 51.3 Hz. Following this, after a minimum of 49.7 Hz frequency reaches the rated 50 Hz at about 17 s.
- After clearing fault, voltage present oscillations of about 7 % in amplitude, being restored at about 7 s.

Study-case 5-b: 250 ms short circuit. Bus 1, 20 kV (Figs. 3, 4)
Although a stable behaviour is observed, high values of voltages and frequency can be expected. Therefore, an adaptation of procedures usually applied to protection devices and wind generators could be required, to assure all network elements remaining under operation:

- Initial frequency peak of about 53 Hz.
- Voltages oscillations of about 10% after clearing fault, being restored in about 8 s.

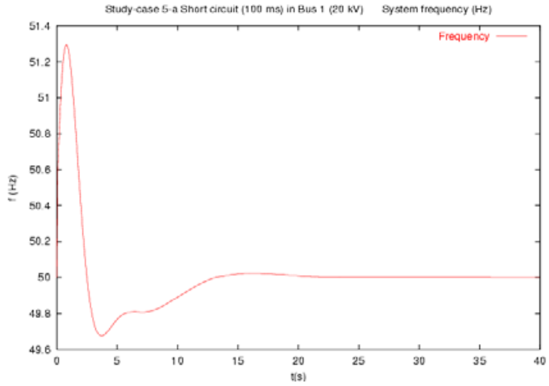

Figure 2: 100 ms short circuit: frequency

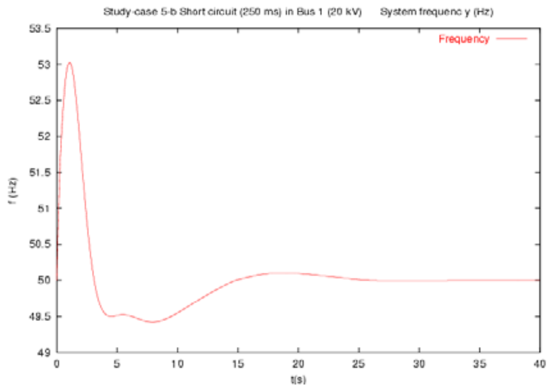

Figure 3: 250 ms short circuit: frequency

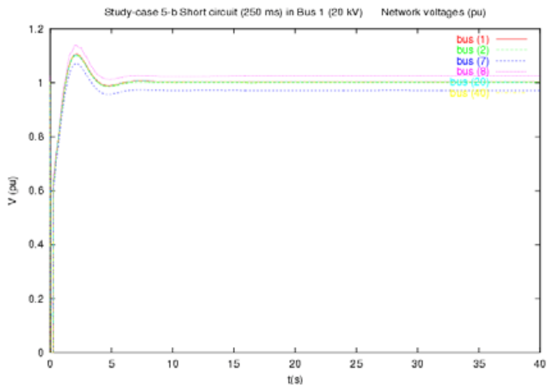

Figure 4: 250 ms short circuit: voltages

Study-case 5-c: Load loss in bus 2 (2.30 MW) (Fig. 5)
Power system behaviour could be rather satisfactory in terms of frequency and voltages values, although a large time evolution could be expected:

- An initial value of 51.2 Hz is observed. Final value of 50.5 Hz is reached at 40 s.
- Voltages oscillations around 2%, being restored at about 15 s.

Study-case 5-d: Diesel unit outage (1.35 MW) (Fig. 6)
In this case, the power system is unstable as a consequence of not enough spinning reserve: network frequency could drop 2 Hz in 10 s.

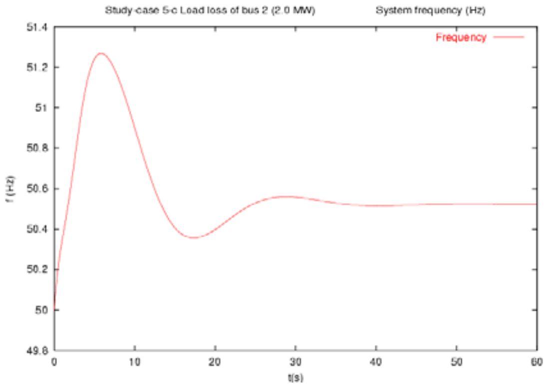

Figure 5: Load loss in bus 2 (2.30 MW) :frequency

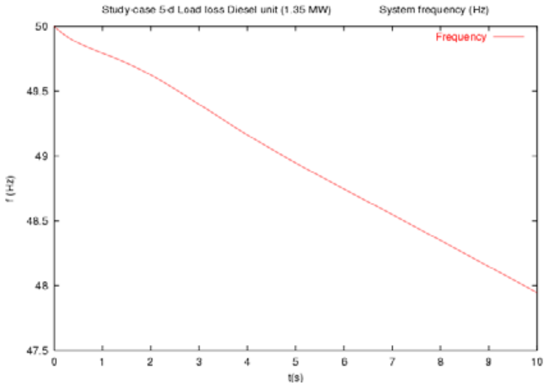

Figure 6: Diesel unit outage (1.35 MW): frequency

Study-case 14-a: 100 ms short circuit. Bus 1, 20 kV (Fig. 7)
A stable behaviour is now observed, although the high inertia constant of the selected hydro turbines causes a very slow restoration of the system frequency:

- An initial value of 50.6 Hz is followed by a slow evolution during about 30 s.
- 7 % voltage oscillations after clearing fault are damped at about 10 s.

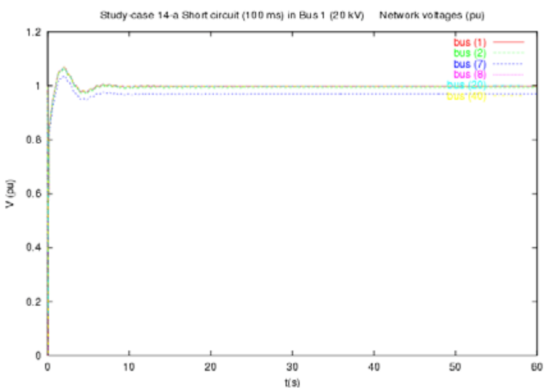

Figure 7: 100 ms short circuit: voltages

Study-case 14-b: 250 ms short circuit. Bus 1, 20 kV (Figs. 8, 9)
High values of voltages are observed and could cause overvoltage protection devices actuation, added to a slow evolution of frequency:

- Voltage oscillations of about 15% after clearing fault could be expected.
- Network frequency reaches final value at about 50 s, with an initial peak of only 51.4 Hz.

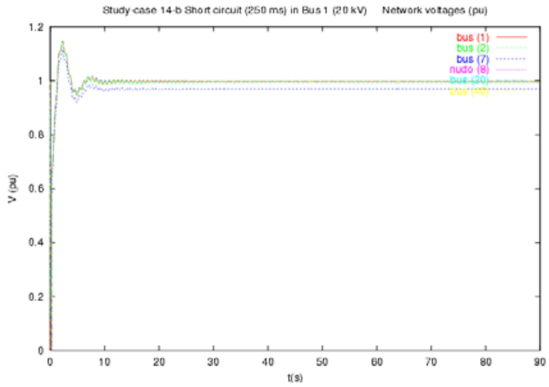

Figure 8: 250 ms short circuit: voltages

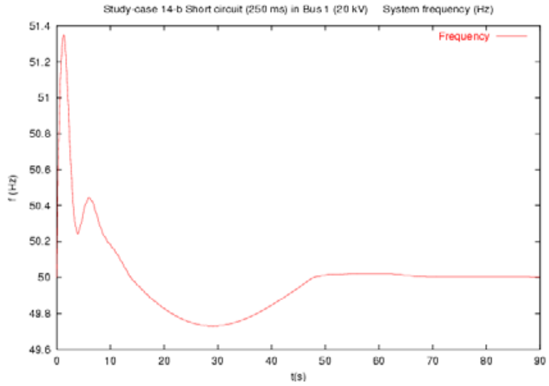

Figure 9: 250 ms short circuit: frequency

Study-case 14-c: Pump disconnection (0.27 MW) (Fig. 10)
Frequency evolution is affected by a large duration. Acceptable values of voltage and frequency deviations:

- Initial maximum frequency of about 50.8 Hz.
- Voltage oscillations of about 0.5 % damped about 10 s later.

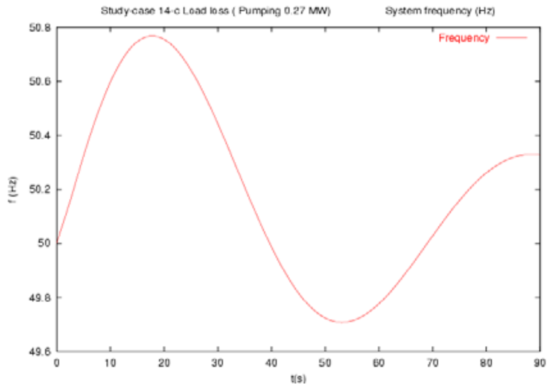

Figure 10: Pump disconnection (0.27 MW): frequency

4 CONCLUSIONS

The above reviewed study-cases are examples from the full set of simulations that have been carried out. The main conclusion is that, in general terms, this power system could present a stable behaviour in most the cases if proper design and required adaptations are performed, to avoid large network frequency and large voltage deviations.

All the information provided by this study will be used for selecting and adjusting operational requirements for wind generators and for operation, control and protection devices to be installed. Hydro turbines speed regulators must be analysed in details for obtaining a good operation. Another tasks to be performed could be the following:

- Selecting procedures and devices for operation that causes only a small impact on network frequency and voltages.
- Adapting operational procedures of the finally selected wind generators, enhancing the typical operational ranges in terms of voltage and frequency deviations, avoiding self-disconnecting from the grid as much as possible.

5 ACKNOWLEDGEMENTS

The work was financed by the utility Unelco-Endesa, S.A. We also thank Instituto Tecnológico de Canarias, S.A. and local authority Cabildo de El Hierro for their contribution to the work.

6 REFERENCES

[1] N. Angulo, F. Díaz, J. Cruz, J. Medina, J. Cidrás, C. Bueno, *Dynamic Analysis of an Isolated Hybrid Wind/Hydro/Diesel power System for Water Desalination*, Wind Power for the 21 st Century, 25-27 September 2000, Germany.

[2] O.I. Elgerd, *Electric energy systems theory: an introduction*, McGraw Hill. 1985.

[3] Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies, *Hydraulic Turbine and Turbine Control Models for System Dynamic Studies*, Transactions on Power Systems, Vol.7, nº 1, February 1992, pp. 167-179.

[4] S. Brereton, D.G. Lewis and C.C. Young, *Representation of Induction Motor Loads During Power System Stability Studies*, AIEE Transactions, Vol. 76, pp.451-461, Aug. 1957.

[5] J. Medina, J. Cidrás, *Influence of Wind Power Fluctuations On Network Voltage And Frequency*, European Union Wind Energy Conference, 1-5 Mar 1999, France.

[6] N. Stavridis, H. Kalagia, P. Pligoropoulos, *Autonomous Hybrid Power Supply For The Greek Islands Of Donousa And Kythnos*, Power-Gen Europe ’97, 17-19 June 1997, Spain.

[7] J. Kabouris, G.C. Contaxis, *Planning of Water Desalination Plant In Conjuction With Wind Energy Penetration In A Small Island System*, European Union Wind Energy Conference, 20-24 May 1996, Sweden.

[8] N. Angulo, J. Medina, J. Cidrás, *A Contribution to the Short-Circuit Analysis of Weak Networks Containing Wind Turbines*, European Union Wind Energy Conference, 2-6 July 2001, Denmark.

[9] W. Youssef, *Hybrid Wind-HydropowerPlant*, European Union Wind Energy Conference, 2-6 July 2001, Denmark.