International Conference on Renewable Energies and Power Quality (ICREPQ'13)
Bilbao (Spain), 20th to 22th March, 2013
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.11, March 2013

Developing a Supervisory Controller for Hybrid Power System: Fernando de Noronha Island Case

Pedro Rosas[1], Caarem Studzinski, Vicente Simoni, Francisco Neves, Alécio Fernandes, Luiz H. A. Medeiros, Fabricio Bradaschia, Gustavo Azevedo, Felipe Guimaraes, Jimens Lima, André Victor, Lucas Cabral, Jose Arimateia e Carlos Soares[2]

[1] Department of Electrical Engineering
Federal University of Pernambuco
Brazil
Phone/Fax number:+55 81 21267100, e-mail: pedro.rosas@ufpe.br

[2] Companhia Energética de Pernambuco CELPE
Av. Joao de Barros, Recife, PE, Brazil
+55 81 32176008

Abstract..

This paper presents the development of a supervisory controller and the main challenges of integrating wind and solar energy into an existing grid with 100% diesel generation. The supervisory controller has been developed for keeping the safety and stability of the network a R&D project financed by the Utility CELPE. The controller keeps the balance of power at all the time and monitors the stability of the network. The controller reads the power production from all sources and define the load in the network and it does two main tasks: the first is to evaluate the stability of the power system; the second is to estimate the diesel production for the next 2 hours. The diesel dispatch is done based on the power and load forecasts. The main features of the supervisory are first of all implemented using a open source software Scada and using the Matlab ® as the main calculus processor, secondly the controller is flexible to operate with different communication protocols, to work with different forecast tools and to act as desired by the power system operator. Actually the power system operator does not accept the automatic control of the diesel units on the other hand, the renewable sources should be automatic controlled, however this feature is flexible in the supervisory controller.

Key words

Supervisory controller, diesel generation, hybrid power system, power forecast.

1. Introduction

Application of renewable energy for power production has several benefits, in small and medium size islands there is an extra benefits of reducing the electricity costs. However, applying renewable power to existing diesel networks lead to special attention on several aspects due to the intermittency of the renewable sources.

Usually the diesel only network that operates 24h has little control. The diesel gen sets share the power and the main aim of the controllers is to optimize the diesel consumption and avoid lack of power including spinning reserve. Traditionally in island systems the operator manually sets the power operation point for secondary control and each diesel governor controls the frequency either using droop control or special configurations of isochronous controller with high communication demands.

Diesel generators have limitations concerning power production, particularly when considering steady state and dynamic operation. When considering stead state operation, one should avoid exceed the limits imposed by the manufacturer, traditionally diesel motors have minimal limits around 40% of active load and some limitations concerning reactive power.

Including renewable energy into this existing network will impact on the diesel operation, depending on the renewable share and on the type and technology used.

Wind energy is by far the most used renewable energy for this end, and it is also the far more problematic considering the diesel operation particularly when using the conventional direct connected wind generators. All the wind fluctuations must be copped by the diesel gen sets, therefore, depending on the share that they supply of electricity, it can be impossible to operate the grid safe and stable.

Solar energy (photovoltaic) has the particularity of being connected through frequency converters. That, to some extent, can be very useful helping the voltage and the stability of the network. However, when considering large amount of load share in diesel networks, can lead to serious problems when it comes to dynamic operation and clouds over the solar panels.

Taking any renewable energy source and combining it with diesel gen sets demands some expertise avoiding unsafe and instabilities when it comes to operation. Although it can have a perfect coupling in terms of energy, coming to operation raises several problems. To avoid the unsafe and instabilities, in this paper it is presented a supervisory controller that monitors the operation and security of the network with the main objective of saving fuel maximize renewable energy.

The supervisory controller is not new to the hybrid power system, it is very necessary to increase the renewable participation in the load sharing. Without a supervisory controller, it is expected to limit the renewable energy in around 20%.

The supervisory controller can manage the power production as well as manage the load, some special loads that can be flexible such as water pumping.

2. Supervisory Controller Aims

The supervisory controller has the main objective to keep the stability and security of the power system. In order to keep the stability of the system the main objective is to keep the power balance every second and monitor the voltage and frequency as well as to keep a spinning reserve.

To keep the balance of active power, the supervisory controller read all power produced and compute the load every second. The system then executes a routine to analyse the data. The data acquisitioned is then delivered to specific modules of power prediction that predict the load and the renewable production and the module that predict the load for the next 120minutes.

The predicted load and production is sent to a module that computes the diesel dispatch for the next 120 minutes. Additionally the supervisory controller has a built-in module of security monitoring. Every sampling of the power is evaluated concerning the power balance add the spinning reserve. Finally all predicted dispatch is evaluated against the same criteria before send to dispatch.

The outputs of the supervisory controller are the dispatch that is showed to the power system operator by the Scada BR an open software that allows different communication protocols and flexibility to communicate with different equipment and systems.

The main structure of the supervisory controller is not new, it is shown in Fig. 1.

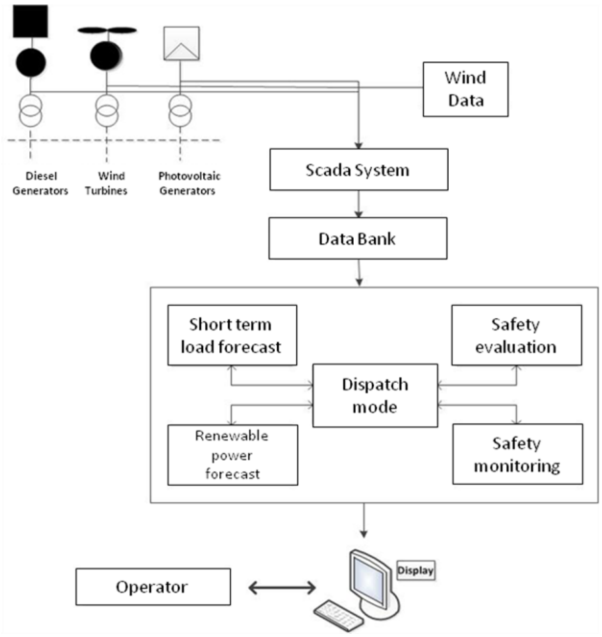

Fig. 1. Main architectural of the supervisory controller.

A. Proposed Supervisory Controller

The diagram showed in Fig. 1 is quite common, and similar controllers for hybrid systems have been developed in several projects.

The proposed supervisory controller differs because it uses a new architecture with large flexibility and with special boundaries related to the problems that the Noronha Island system demands.

For the supervisory controller, it is necessary to have the ability to communicate with different equipment from diesel gen sets to wind turbines and solar photovoltaic inverters as well as to the existing Scada System from the Utility.

The supervisory needs also to be flexible concerning the calculations and the modules, for that reason, it has been decided to implement the calculus modules in Matlab® using m-files.

The modules for prediction of load and renewable power have been implemented with two models. The first model uses a persistency model that estimate the power for the next 120 minutes based on the actual power and on the expected behaviour for the time and date.

A second model, based in Artificial Intelligence has been implemented, where the neural network was trained based on the available history of load. The wind and solar were obtained from data base and they were implemented into the models by the primary source, and a second part models the power output for each time step ahead.

The models are developed based on the wind turbine and the solar panels types to be installed. That means that the active and reactive power for each moment, as well as the abilities from each equipment are taken into account. For instance, the ability for active power regulation is taken into account.

3. Noronha Island System

The Fernando de Noronha Island is located 550km from the coast of the Northeast of Brazil. It has 3500 people living there. The island has 5x3km.

A major part of the island is a national park for environmental protection. All the waste in the island shall be transported back to the continent, and there are very restricted norms for the protection of the natural environment.

For instance all the electricity supplied in the Island is produced by 5 diesel gen sets as presented in the Table I.

Table I. Diesel gen sets in Noronha Island.

FUEL	INSTALLATION	RATED POWER
Diesel	2007	1.608 kVA / 1.286 kW
Diesel	2007	1.125 kVA / 900 kW
Diesel	2007	1.125 kVA / 900 kW
Diesel	2008	1.608 kVA / 1.286 kW
Diesel	2012	1.608 kVA / 1.286 kW

Several attempts were done to include renewable energy in the island. Historically two medium sized wind turbines were installed. In 1992 a 75kW classical Danish wind turbine, i.e. an asynchronous generator, grid tied wind using capacitor banks was installed, and unfortunately was put down due to problems. Another wind turbine, of 225kW was installed in 2001, again a typical Danish wind turbine was installed, and worked until 2009 when it was hit by a lightning stroke and burned down.

The installation of these two wind turbines in the Island showed that even with the small amount of energy from intermittent energy it does impacted in the normal operation of the utility. There were several cases of operational problems that were solved by turning off the wind turbine manually, as there was not an automatic controller.

During the years near 2000 there were also installed two photovoltaic systems, with rated power of 10kW each.

A summary of the load from the island is shown in Table II.

Table II. Summary of the load.

	DAYLY AVERAGE	SUMMER AVERAGE	WINTER AVERAGE	ANUAL 2010
Energy Consumption kWh	32.755	34.000	31.900	11.955.827
Maximum Load (kW)		2.500	1.950	

As the national grid procedures, the network in the island should have the same quality as the continent, i.e. very small frequency and voltage deviations.

Additionally, the regulations from the National power authority (ANEEL) demands that the utility works at very low level of energy disruptions. There are very expressive fines case the utility does not comply with the regulation. So, the loss of load in the system is not an option. All the load should supplied at any time.

The island has natural resources for solar and wind power that justify its use. Fig. 2 shows the wind energy potential for the Fernando de Noronha Island done in the project.

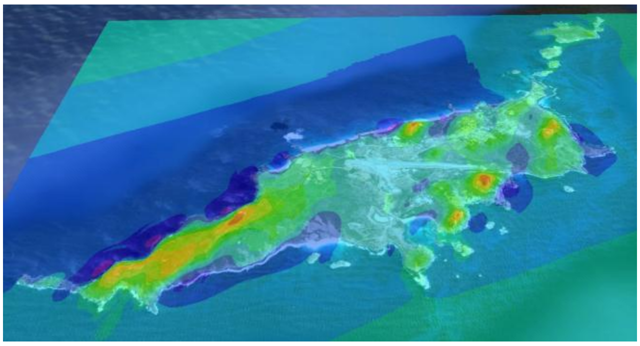

Fig. 2 Fernando de Noronha Island wind power atlas.

Fig. 3 shows the load and the natural resources for the Noronha Island.

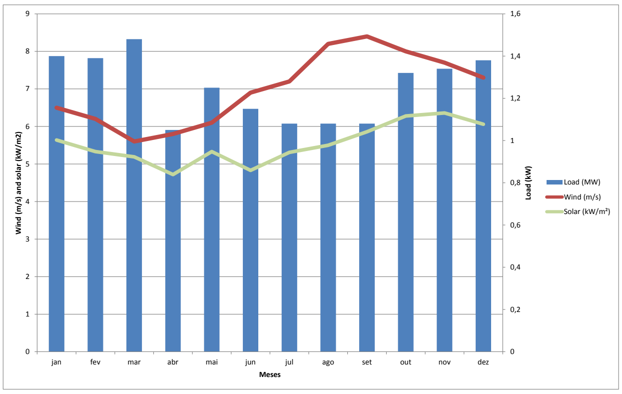

Fig. 3. Load and renewable resources.

As it is felt, there is a good coupling among wind, solar and the load. The plans to Fernando de Noronha Island are at this moment 500kW photovoltaic solar panels. There were plans to install three large wind turbines but these plans are postponed till further notice.

Finally, considering the proposed system, and the possibility of having a larger hybrid system in the Island, the utility founded this R&D project to develop the supervisory controller to accommodate and allow safe operation of the power system with these renewable sources.

4. Neural Network Training

The developed supervisory controller was trained with MATLAB toolboxes neural network using Levenberg-Marquardt and Resilient Backpropagation methods, which the main data are shown in Figure 4.

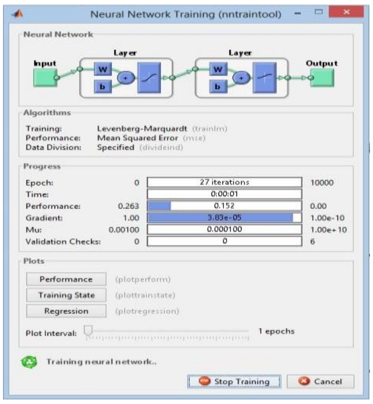

Fig. 4. Neural Network Training using MATLAB toolbox.

The neural networks were trained with 01 hidden layer and with the number of neurones in each layer varying from 01 to 30, considering two type of normalization.

- Normalization 1: normalizes data input between 0 and 1, by:

$$y = \frac{x - x_{\min}}{x_{\max} - x_{\min}}$$

- Normalization 2: normalizes data input between 0.1 and 0.9, by:

$$y = \frac{0.8x + 0.1x_{\max} - 0.9x_{\min}}{x_{\max} - x_{\min}}$$

Tables III and IV show the average and maximum errors of the simulations.

Table III. Levenberg-Marquardt method.

NORMALIZATION	NUMBER OF NEURONES IN THE HIDDEN LAYER	AVERAGE ERROR (%)	MAXIMUM ERROR (%)
Normalization 1	28	2.98	59.73
Normalization 2	25	3.00	36.14

Table IV. Resilient Backpropagation method.

NORMALIZATION	NUMBER OF NEURONES IN THE HIDDEN LAYER	AVERAGE ERROR (%)	MAXIMUM ERROR (%)
Normalization 1	30	4.29	72.63
Normalization 2	29	4.07	64.61

The average errors are considered satisfactory which indicate that the using of neural networks with load forecast, wind velocity and solar power input can be used in the supervisory controller system. The maximum errors indicate that some input data are not trustable and need previous processing to eliminate or attenuate these errors.

5. Validation Data

To validate the parameters received from ScadaBR by the Dispatch program, some modifications were made to verify the coherence of the input data. Table V shows the input data for validation purposes.

Table V. Input data to validate the supervisory controller system.

Dispatch parameter	Interval	Unit
Month	≤ 12 and ≥ 1	
Day of the week	≤ 7 and ≥ 1	
Hour	≤ 23 and ≥ 0	
Minute	≤ 59 and ≥ 0	
Second	≤ 59 and ≥ 0	
Load Power	≤ 3000 and ≥ 0	Kilowatt (kW)
Solar Power	≤ 400 and ≥ 0	Kilowatt (kW)
Wind Velocity	≤ 30 and ≥ 0	Meters per second (m/s)

Table V presents the input data boundaries for the Dispatch program which are used to verify if any of the input data sent to the Dispatch program is out of limits (which can cause instability and erroneous dispatch). If at least one of the input parameters is out of limits it is informed that corrections have to be done, otherwise, the system is blocked and the dispatch is void. This allows instability of the system and avoid collapse of power generation.

6. Conclusion

The supervisory controller has been developed in a R&D project to implement the renewable energy in the Fernando de Noronha Island.

The paper has presented the results of testing the supervisory controller system and the main features developed. The supervisory controller system was tested and validated using two methods of neural network which presented quite good results considering the average errors.

After some considerations considering the input data, the system presented to be stable and accurate and has been installed in the Fernando de Noronha Island.

Acknowledgement

The authors would like to acknowledge the support from CELPE Utility in the R&D project: development of a Supervisory Controller for Fernando de Noronha.

Relevant References

MENDIS, Nishad et al. ANNUAL. A Control Approach for Voltage and Frequency Regulation of a Wind-Diesel-Battery based Hybrid Remote Area Power Supply System. CONFERENCE ON IEEE INDUSTRIAL ELECTRONICS SOCIETY, 36, 7 – 10 de novembro de 2010, Arizona – EUA. Austrália: School of Electrical, Computer and Telecommunications Engineering of Wollongong, p. 1 – 7.

HARUNI, A. M. O et al. Dynamic Operation and Control of a Hybrid Wind - Diesel Stand Alone Power Systems. Applied Power Electronics Conference and Exposition (APEC). 21 – 25 feb. 2010, EUA. Austrália: Centre of Renewable Energy and Power Systems (CREPS) University of Tasmania, p. 162 – 169.).

KAMAL, Elkhatib et al. Electrical Power and Energy Systems: An Intelligent Maximum Power Extraction Algorithm for Hybrid Wind–Diesel Storage System. Science Direct, Egito, v. 32, p. 170 – 177, 2010.

Rosas, Pedro; Lemos. W; Pereira, A.; Barros, R.; Feitosa, E. : Problems of planning hybrid **wind–diesel power systems**. In: Proceedings of IEEE transmission and distribution conference Latin America; 2004. p. 617–22.

UHLEN, K.; FOSS, B. A.; GJOSAETER, O. B. Robust Control and Analysis of a Wind-Diesel Hybrid Power Plant. IEEE Transactions on Energy Conversion, Trondheim - Noruega, v. 9, n. 4, p. 701 – 708, dez. 1994.

Pereira, Alexandre de Lemos, Modular supervisory controller for hybrid power systems, Ph.D. Thesis, Lyngby, Risoe DTU, june, 2000.