FREQUENCY CONTROL TECHNIQUES FOR ELECTRICAL POWER NETWORKS WITH HIGH WIND ENERGY GENERATION EMPLOYING FUZZY LOGIC CONTROLLERS

1. SARAGADAM CHANDU,2. MUTTA MURALI TARUN,3. RONGALI CHANDU,
'4. PURIA KIRAN KUMAR *5. MURARI PAKKI, HEAD OF THE DEPARTMENT
DEPARTMENT OF ELECTRICAL AND ELETRONICS ENGINEERING
SANKETIKA VIDYA PARISHAD ENGINEERING COLLEGE,VISAKHAPATNAM

ABSTRACT: - In electrical power systems, increasing amounts of wind energy penetration present new operational issues. Maintaining the generation-demand balance is one of these issues in order to keep the system frequency within reasonable limits. Utilizing systems for demand side response, which are an addition to the conventional generation side power-frequency regulation, is one way to address this problem. The effects of responsive electric vehicle (EV) charging procedures on reducing the impact of fluctuating wind power generation on frequency stability is discussed in this research. To do this, a model of a hybrid electrical power system located on an island is used to study the frequency response to various wind conditions and EV charging procedures and Fuzzy Logic Controller is used for the Better Frequency response and Faster settling time. The findings demonstrate that even a small portion of the total demand participating in frequency control can have a big influence.

Index Terms: Electric vehicles demand response (DR), vehicle to grid (V2G), decentralized control, primary frequency control, Fuzzy Logic Controller.

I. INTRODUCTION

Increasing renewable generation has been a trend in power generation across the world, contributing to the environmental sustainability of electric power, reducing greenhouse gases emissions and energetic dependence of some countries. However, it also presents difficulties for conventional power system rules [1], such as reducing the system's inertia when renewable energy sources (mostly solar and wind generation, concealed by power electronics) take the place of synchronous generation [2].

Due to variations in their major power source, these power sources are also subject to significant swings at the same time. For solar energy, this could be brought on by a cloud that is moving swiftly across the sky and partially obscuring a solar array, whereas for wind energy, this is primarily caused by the normal gusts that occur in any wind profile.

For a conventional power system to operate, generation facilities must react to frequency variances by adapting total power generation to the consumption at any given time. The swing equation describes how the frequency behaves in power systems [3]:

$$PG - Pl = 2 * Hs * w * \left(\frac{dw}{dt}\right) (P.U)$$

Where PL is the amount of power consumed by loads, PG is the amount of power generated by generators, Hs is the system's inertia constant, and is the system's frequency. The proposal in this study is to use the recharging of electric vehicles to improve the system frequency response by modulating the recharge power in accordance with the system frequency state. As can be seen from the system frequency, an increase in power production is equivalent to a decrease in power consumption.

Several authors have thought about earlier work on this subject, including V2G as a service for system stability. While [5], [6] consider frequency response to a recharge strategy based on the Battery State of Charge (BSOC), [4] already considered the use of EVs on frequency regulation in 2009, considering a sudden drop in wind speed, using a

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 04 | April - 2023 Impact Factor: 8.176 ISSN: 2582-3930

dead band (0.1 Hz) and constant droop for the frequency response.

When it comes to the system, [7], [8], and [9] focus on smaller power systems on islands, whereas [10], [5], and [6] consider systems with numerous interconnected areas. Most of these studies, like [11], consider a centralized approach, splitting the error signal into its low and high frequency components and sending them to conventional generators or electric vehicles in accordance. However, all of these studies take rather large disturbances into account, like a sudden loss in wind power generation. The response is always linear with respect to the frequency deviation, too.

The literature has suggested a number of typical LFC controllers, including PI and PID controllers. Conventional controllers, however, are unable to deal with the complexity of the power system network's uncertainties. Therefore, various intelligent controllers, such as fuzzy logic-based, artificial neural network-based and adaptive neuro-fuzzy inference system-based controllers, have also been used for LFC.

A lot of academics have also been interested in hybrid controllers like fuzzy-PID in addition to these controllers Fuzzy logic-based controllers are among those that can achieve the desired performance while handling the greatest amount of uncertainty in the system parameters. Numerous research works have used fuzzy logic technique for LFC due to their dependability simplicity, and robustness.

In this study, we present an isolated power system that is based on the Galapagos Islands' San Cristobal's electrical power system, which comprises of three 800 Kw turbines and three 813 kVA synchronous diesel generators [12]. Using just locally accessible observations, we introduce the nonlinear response to frequency variations and contrast it with the linear response.

II. SYSTEM AND MODEL

The island of San Cristobal's electrical power system is detailed in [12] and has been characterised as three subsystems made up of the load, the synchronous generation, and the wind power generation, respectively.

The entire model is run at a voltage of 1 kV, and for the sake of simplicity, the influence of passive parts like transformers, cables, and lines has been disregarded. The "Specialised Power Systems" package from Sims cape was used to implement the model in MATLAB/Simulink [13].

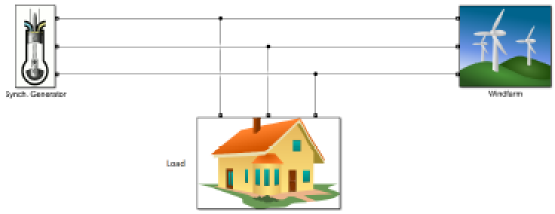


Fig. 1: General diagram of the power system model, with its three subsystems

A. Diesel generation

The Specialised Power Systems Synchronous Machine up Standard block, which simulates a three-phase salient pole generator, has been used to create the subsystem representing the diesel generation as a single synchronous generator. Based on the MathWorks example of a power turbine, the block Excitation system serves as the exciter. Figure 2 illustrates how the diesel motor has been described by a time delay and first order transfer functions for its control and actuators in accordance with [12]. The tables I and II show the parameters that were employed

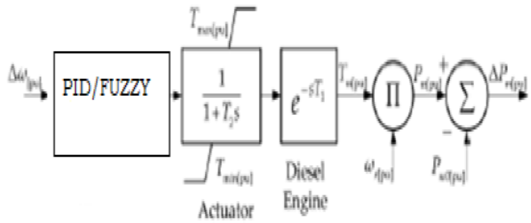


Fig. 2: Diesel motor model

B.Wind farm

Using the power: wind fig ago model from MATLAB/Simulink, as indicated in figure 3, the wind generators have been represented as DFIG.

The machines' parameters are enumerated in III, and it is presumptive that they are run at a set point of Q = 0 var to maximise power output.

Table I: Diesel Generator parameters

Sn=813kva	Xd(p.u)=1.25
Un=1Kv	X'd(p.u)=0.38
Fn=50hz	X''(d)=0.3
Hdg(s)=0.4208	Xq(p.u)=0.7
F(p.u)=0.01	Xq''(p.u)=0.3
P=2	Xl(p.u)=0.1
Rs(p.u)=0.017	T'd(s)=3.35,T''d,q(s)=0.095

TABLEII: Synchronous Generator Governor Parameters

T1(s)=0.024
T2(s)=0.1
T3(s)=0.01
Kp=2.294
Ki=1.458
Mmax(p.u)=1.1
Mmin(p.u)=0

The three wind turbines are situated near to one another, 125 m apart, and aligned on an east-west axis. The wind profile incident to each of them is presummated to be the same, but delayed in relation to the prior wind turbine by

$$t = \frac{125(m)}{Um\left(\frac{m}{s}\right)} * Sin(\emptyset)$$

Where Um is the average wind speed and ϕ the angle of incidence.

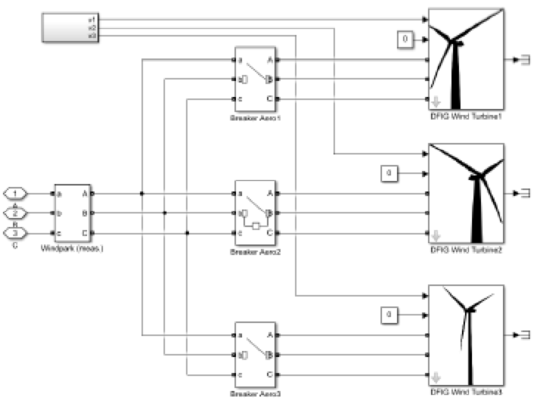


Fig. 3: Model of the wind farm subsystem

C.Load

Figure 4 depicts a model of the system's load, which may be divided into two categories:

1) Standard load: Three different categories have been combined to represent the conventional load in models:

loads with a fixed active power P and no variable reactive power Q.

Constant Z loads that are impedance-modelled.

Inertial loads comprised of a half-loaded, equivalent asynchronous motor with a SAM-rated power and an inertia constant of 0.5 s.

A capacitive load that produces 30% of SAM as reactive power helps to partially offset the generator's reactive power. Each of these loads will consume around a third of the total electricity required.

Table III: Wind Turbine Parameters

Parameters	Symbol	Value
Rated power	Pbase	800Kw
Rated Wind	Vbase	10m/s
Active Power	PVbase	697Kw
Pole Pairs	P	2
Frequency	fn	50hz
Inertia Constant	Heq	4.18s
Bladé Pitch(min/max)	β	0/88
Max Blade pitch speed	**β ***	10/s
ControllerGains	Kp/Ki	150/25
Speed Controller Gains	Kp/ki	0.3/8

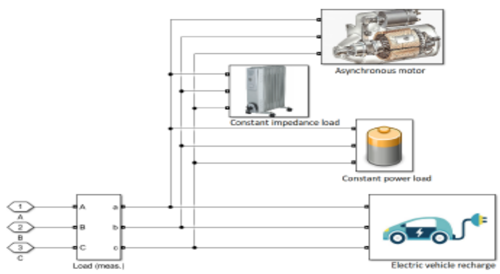


Fig. 4: Model of the load subsystem

2) Electric vehicle: The electric car is a specific kind of load in the system since it serves as a tool for frequency regulation by controlling its power consumption. The total power consumption for electric cars PEV is believed to have a reference value (PEV ref) that can be altered in response to frequency deviations:

$$Pev = Pevref + \Delta Pfv(ref)$$

Our primary objective is to contrast various ΔPev functions and their contributions to frequency stability without interfering with steady-state control or the vehicle's net charging process. The following principal presumptions have been made in the design of these alternatives:

The mean value of the wind-induced frequency deviation is zero.

When compared to the system dynamic reaction, the response time of an electric vehicle recharge is insignificant.

The batteries can be charged or discharged with no energy limitations.

Due to the following restrictions, any charging technique used is oddly balanced with respect to frequency deviation:

The needed power must be the rated one when f = 0, and as a result, the deviation must also be zero.

• A dead band of 10 MHz has been implemented to prevent constant activations for modest quantities of frequency variation.

• The demanded power must be at its peak at a specific frequency deviation value, fmax, which implies that the absolute value of the deviation, PEV max, must also be at its maximum.

The parameters fmax = 0.25 Hz and PEV max = 50 kW have been selected for the model that has been put into practise. Figure 5 illustrates the implementation and comparison of three distinct response options.

- The proportional response (blue line in figure 5) is the illustration that appears the most frequently in the literature (e.g., [8] or [7]), and it consists of a linear increase in the power deviation with frequency, the previously mentioned dead band around zero, and a maximum power output restriction.
- Soft Control: The gradual transition around zero provided by soft control (the green line in figure 5) enables the removal of the dead band. Small deviations cause a milder reaction, but it catches up at about 40% of fmax.
- Aggressive control (red line in figure 5) reacts more quickly to minor frequency changes while maintaining the dead band at zero.

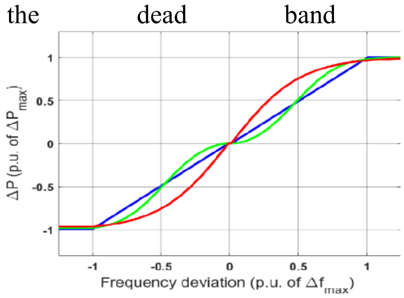


Fig 5 Overview of different control strategies: proportional (blue), soft (green) and aggressive (red)

D.Fuzzy Logic Controller

Jang proposed the acronym ANFIS, or adaptable neuro-fuzzy inference systems, in 1997. ANFIS is an adaptable system that combines the advantages of fuzzy logic and neural networks. We can function in unclear and uncertain situations thanks to fuzzy logic. However, fuzzy logic generates unpredictable results based on random rule bases and random membership functions. Fuzzy logic incorporates the artificial neural network approach to prevent random output.

Fuzzy logic's adaptive capabilities are introduced through this fusion. Using the back-propagation technique of a neural network, the appropriate rule base and membership functions in ANFIS are chosen in accordance with the relevant application. As a result, ANFIS is a fuzzy inference system that makes it easy to adjust membership function parameters using the backpropagation technique or any least-squares-based algorithms. The fuzzy system gains knowledge from the data it will use by doing this.

In the case of the ANFIS architecture, the error signal and rate of change of the error signal are the two inputs that are selected. The membership functions are chosen as triangular ones with a corresponding universe of discourse range between [-1, 1] for the input and output variables. ANFIS was initially proposed using type-1 (T1) fuzzy systems. However, addressing complex and unpredictable systems presents several challenges for the T1 fuzzy logic system. T2 fuzzy logic system has therefore been used in ANFIS in this work to address these issues. T2 fuzzy sets' membership functions are used to identify them.

T2 fuzzy logic systems fall within the category of fuzzy logic systems that have at least one T2 fuzzy set. Interval T2 (IT2) fuzzy set is the most used type of T2 FS and has a low computational cost. Lower membership function (LMF) and upper membership function (UMF) limit IT2 fuzzy sets. In this study, the ANFIS was trained utilising information gathered from the IT2 fuzzy logic system.

The rule base with 9 rules, as stated in Table VI, has been employed for the IT2 fuzzy logic system. We choose six triangle membership functions for input and output variables. ANFIS has been used for LFC with the gbell membership function after training to achieve the best outcomes.

E. Validation

By simulating the unexpected loss of two wind turbines, the model has been shown accurate. Figure (5) in [12] depicts the scenario and the actual frequency behaviour, while Figure 6 shows the outcomes of recreating it in our model. Both findings have been deemed comparable enough to support the concept.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 04 | April - 2023 Impact Factor: 8.176 ISSN: 2582-3930

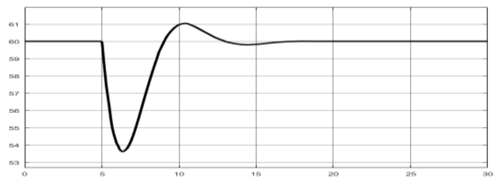


Fig. 6: Frequency deviation at loss of wind generation (model validation)

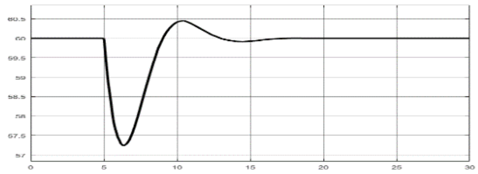


Fig 7 Frequency Response using Fuzzy Logic Controller

III SCENARIOS

It is crucial to employ wind speed data collected at an abnormally high sample rate in this area of research. The recordings from Terborg, Denmark [14], at a height of 60 m, offer excellent data since they have adequate temporal resolution (25 sps), are located close to the coast, and are free of any notable geographic accidents that would have disturbed the wind. The wind turbines were exposed to the wind profile for 600 s in each simulation, causing frequency aberrations in the system. Table IV displays the data for the winds that are the most pertinent.

Table IV: Wind Data Parameters

Wind Profile	W1	W2	W4	W5
U(m/s)	5.25	11.61	4.61	10.03
SD(m/s)	0.1181	0.6483	0.4973	1.7150
T1(%)	2.25	5.58	10.80	17.09
Umin(m/s)	4.84	9.85	2.77	6.13
Umax(m/s)	5.68	13.93	6.23	13.53

Average wind speed (U) and turbulence index (TI), two distinct criteria, were used to develop the wind scenarios that were to be taken into consideration. This allows for four alternative wind speed scenarios (low, high, and turbulence), each with a base load of 1900 kW, as indicated in table V.

Table V: Data for the Presented Scenarios

Parameters	Symbol	Value
No.of Wind Turbines	nDFIG	3 W1,w4 2 w2,w5
Wind power Generation	Pw(kw)	200 1600
Diesel Power Generation	PGs(kw)	1700 300
Rated power of AM	Sam	1500kw
Asynchronous Motor load	Pam	700kw
Constant Impedance load	Pz	600kw
Constant Power Load	Ps	600kw

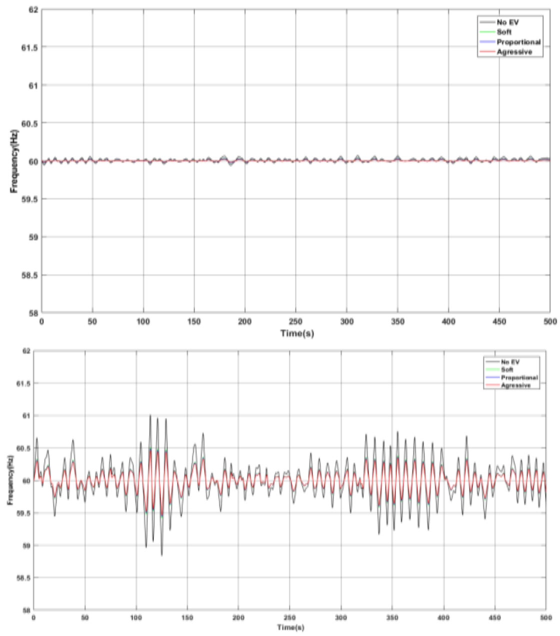
Therefore, a total of 16 scenarios are considered: 4 wind profiles and 4 load scenarios (3 control strategies and no control).

Table VI Fuzzy Logic Rule Based

	De/dt					
E	PS	PM	PL	NL	NM	NS
S	PS	PS	PM	NL	NM	NS
M	PS	PM	PM	NL	NL	MN
L	PM	PM	PM	NL	NL	NL

IV RESULTS

Figure 8 displays the evolution of the system frequency for each scenario that was taken into consideration.



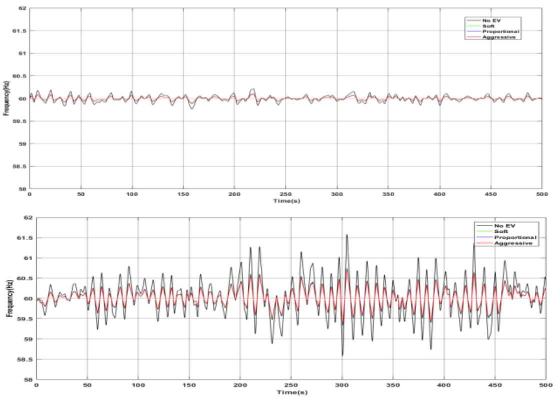


Fig8: Frequency Evolution for all study Scenarios

While the average frequency was consistently close to its rated value, its behaviour (expressed as the amplitude of its oscillations and its standard deviation) deteriorates with increasing wind oscillations, but especially with increasing wind speed. An increase in wind speed results in an increase in wind power generation and, consequently, in wind power penetration, compounding the influence on the frequency because the load is the same in all cases. While little difference can be confirmed between the various strategies that have been compared, it is already obvious that the load's participation in frequency regulation has a positive impact on its behaviour, reducing the maximal frequency error and its standard deviation from the rated value. Comparing the percentage of the frequency that falls within an allowed range—for this study, 60 Hz 0,15 Hz, which indicates a 0.25% deviation from the rated value and is determined by the Ecuadorian electric system regulator [15]—is one technique to assess the effectiveness of frequency regulation.

TABLE VII: Fraction of time with the frequency within acceptable range

	W1	W2	W4	W5
No Control	1	0.3462	0.9480	0.2329
Proportional	1	0.7272	0.9983	0.4729
Aggressive	1	0.8030	0.9999	0.5325
Soft	1	0.7557	0.9995	0.4967

Table VII demonstrates that even without the demand participating in frequency regulation, the frequency remains in the range of 0.15 Hz when wind generation is minimal and the wind profile is stable (w1).

With demand side participation in frequency regulation, the frequency drifts out of range about 5.2% of the time in the scenario with wind profile w4, which has about the same average wind speed (and consequently about the same wind power generation) but with a higher TI (that is, wider spread values around the mean.

Depending on the chosen control approach, the impact is considerably bigger in the high wind speed cases (w2 and w5), more than doubling the frequency percentage that remains within constraints from roughly 35% to 72%–80% for w2, and from 23% to 47%–53% for w5. Although this behaviour is still unsatisfactory, it is a vast improvement over the demand side of having no frequency response. It's also important to note that the load participating in frequency regulation makes up less than 2.5% of the entire load 50 kW over a demand of 1900 kW.

CONCLUSION

This work has demonstrated that EV involvement is feasible and significantly enhances the frequency behaviour of a small power supply. Even a tiny percentage of the overall demand (50 kW over 1900 kW in the case investigated) participating in frequency management has a substantial impact on frequency stability, but it is insufficient to meet the needs of the electrical system in all circumstances. However, the presence of a demand response to frequency variances is significantly more important than the differences between the various management schemes. Work Shows the Effectiveness of Fuzzy logic Controller in Controlling the Frequency Deviation Compare to Conventional Controller. The objectives of this work are to identify different approaches for demand participation in frequency regulation, detect the system's regulatory needs based on frequency measurements, including other types of perturbations (such as photovoltaic PV panels fuel cells, super capacitors), and incorporate demand response with frequency regulation on the side of renewable energy generation.

REFERENCES

[1] H. Ibrahim, M. Ghandour, M. Dimitrova, A. Ilinca, and J. Perron, "Integration of Wind Energy into Electricity Systems: Technical Challenges and Actual Solutions," *Energy Procedia*, vol. 6, pp. 815–824, 2011.

[2] M. P. Jadhav and V. N. Kalkhambkar, "Frequency Regulation by Electric Vehicle," in *2018 International Conference on Current Trends towards Converging Technologies (ICCTCT)*, (Coimbatore), pp. 1–6, IEEE, Mar. 2018.

[3] J. D. Glover and M. S. Sarma, *Power System Analysis and Design*. Pacific Grove, CA: Wadsworth/Thomson Learning, 3rd ed ed., 2002.

[4] J. A. Pecas Lopes, P. M. Rocha Almeida, and F. J. Soares, "Using vehicle-to-grid to maximize the integration of intermittent renewable energy resources in islanded electric grids," in *2009 International Conference on Clean Electrical Power*, (Capri, Italy), pp. 290–295, IEEE, June 2009.

[5] Y. Ota, H. Taniguchi, T. Nakajima, K. M. Liyanage, J. Baba, and A. Yokoyama, "Autonomous distributed V2G (vehicle-to-grid) considering charging request and battery condition," in *2010 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe)*, (Gothenburg, Sweden), pp. 1–6, IEEE, Oct. 2010.

[6] H. Liu, Z. Hu, Y. Song, and J. Lin, "Decentralized Vehicle-to-Grid Control for Primary Frequency Regulation Considering Charging Demands," *IEEE Transactions on Power Systems*, vol. 28, pp. 3480–3489, Aug. 2013
.

[7] P. M. R. Almeida, J. A. P. Lopes, F. J. Soares, and L. Seca, "Electric vehicles participating in frequency control: Operating islanded systems with large penetration of renewable power sources," in *2011 IEEE Trondheim PowerTech*, (Trondheim), pp. 1–6, IEEE, June 2011.

[8] N. Neofytou, K. Blazakis, Y. Katsigiannis, and G. Stavrakakis, "Modeling Vehicles to Grid as a Source of Distributed Frequency Regulation in Isolated Grids with Significant RES Penetration," *Energies*, vol. 12, p. 720, Feb. 2019.

[9] G. Delille, B. Francois, and G. Malarange, "Dynamic Frequency Control Support by Energy Storage to Reduce the Impact of Wind and Solar Generation on Isolated Power System's Inertia," *IEEE Transactions on Sustainable Energy*, vol. 3, pp. 931–939, Oct. 2012.

[10] Wenqi Tian, Jinghan He, Liyong Niu, Weige Zhang, Xiaojun Wang, and Z. Bo, "Simulation of vehicle-to-grid (V2G) on power system frequency control," in *IEEE PES Innovative Smart Grid Technologies*, (Tianjin, China), pp. 1–3, IEEE, May 2012.

[11] H. Liu, K. Huang, Y. Yang, H. Wei, and S. Ma, "Real-time vehicleto- grid control for frequency regulation with high frequency regulating signal," *Protection and Control of Modern Power Systems*, vol. 3, p. 13, Dec. 2018.

[12] D. Ochoa and S. Martinez, "Proposals for Enhancing Frequency Control in Weak and Isolated Power Systems: Application to the Wind-Diesel Power System of San Cristobal Island-Ecuador," *Energies*, vol. 11, p. 910, Apr. 2018.

[13] "MATLAB and Simscape Power Systems Toolbox, release 2018b." The MathWorks, Inc., 2018.

[14] K. S. Hansen and G. C. Larsen, "Database of wind Characteristics (DTU - Department of Wind energy)." http://winddata.com/.

[15] Agencia de Regulaci´on y Control de Electricidad, "Procedimientos de Despacho." https://www.regulacionelectrica.gob.ec/wpcontent/ uploads/downloads/2015/10/ProcedimientosDespach o.pdf