A 800 kW wind-diesel test bench based on the MADE AE-52 variable speed wind turbine

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***Abstract*—A field work have been made about the practical installation of a wind-diesel autonomous power system. A remarkable innovation on the control of the latter wind-diesel system is the ability of taking advantage of the kinetic energy available from the wind turbine. With such an extra energy, a power quality improvement can be achieved in the presence of load commutations. Besides of that, a convenient power sharing out can be obtained, allowing a high renewable energy penetration and fuel savings. Several results show the behaviour of the whole system, apart of the power quality improvement.**

***Index Terms*—Renewable hybrid system, isolated power system, power quality, diesel generator, wind turbine.**

I. Introduction

As described in [1], the Spanish company MADE Tecnologías Renovables S.A. developed a new high performance stand-alone wind-diesel generator system based on a 800 kW variable-speed, variable-pitch wind-turbine MADE AE-52 controlled with a DSP control board.

The proposed wind–diesel system is arranged according to the general elements shown in Fig. 1, instead of those in conventional hybrid systems [7],[8]. There are two main objectives of such a configuration. On one hand, a convenient control of the power electronic drive, makes possible that the wind turbine could operate as a current source, delivering an extra energy due to its high kinetic energy. The latter behaviour cause that it is possible to maintain the system stability in the presence of load commutations. On the other hand, the use of wind energy in autonomous or island power systems together with diesel generators involves a pollution reduction and also they are highly cost-effective due to the dramatic reduction of diesel fuel consumption and transportation.

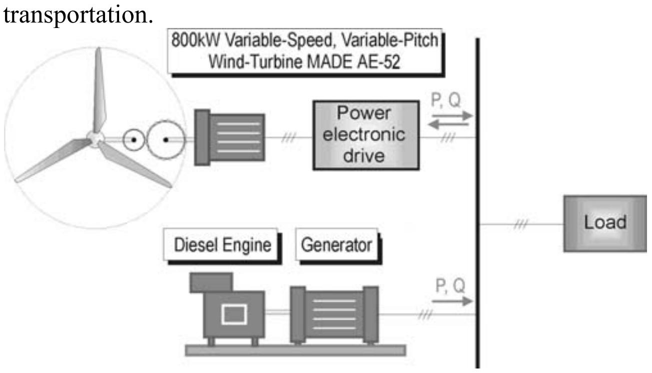

Fig. 1. Stand-alone wind-diesel generator system based on a 800kW variable speed, variable pitch wind turbine MADE AE-52.

Otherwise, to achieve the previous objectives, a suitable control system based on two DSP's electronic board, for the wind turbine is needed according to the type and amount of demanded energy by consumers. Therefore, several control strategies are proposed and discussed over the results, obtained not only from simulations but also obtained from laboratory emulation [11] and real implementation.

The base control schema is shown in Fig. 2, where power control was substituted by torque control according to requirements on power quality parameters and load demand [9],[10].

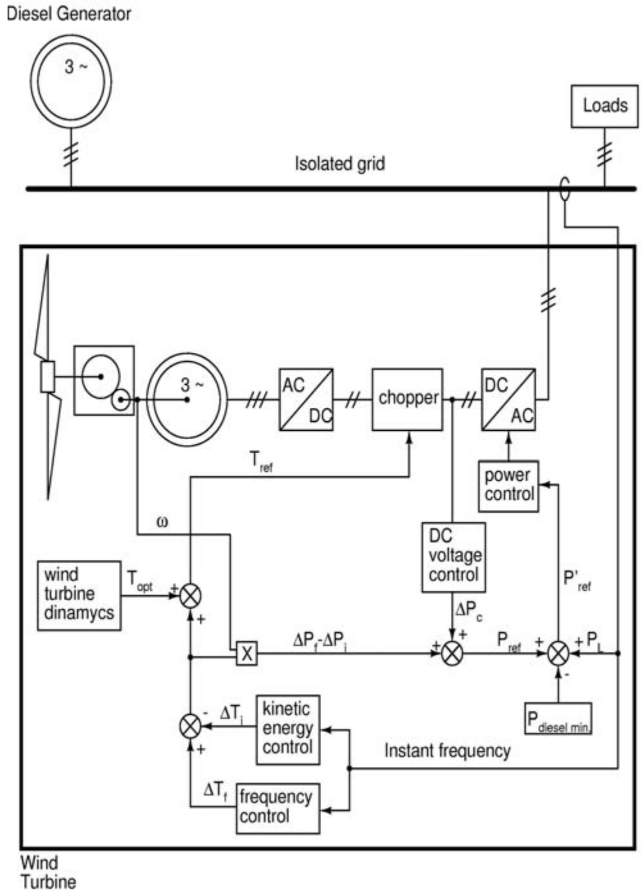

Fig. 2. Base control scheme for MADE's AE-52 wind-turbine.

As deduced in several studies [1]-[6], simulations over similar wind–diesel systems show that improvements over power quality can be succeeded, specially with respect to frequency and voltage variations, phase unbalance and THD decreasing.

In the present work, a wind–diesel system workbench have been mounted as a real test system in a south Spain wind farm (Monteahumada, Tarifa). The purpose of the real system was to test the validity of previous simulation and scaled emulation results as part of field works.

Several results obtained, shown the suitability of the proposed wind–diesel control strategies and hardware system regarding to the improvement of the power quality in a isolated power system. There are also important conclusions about possible drawbacks that could be presented by the real installation of such a proposed system.

II. Test-Bench Description

The test-bench has been built in Monteahumada's wind-farm where we use a wind turbine (AE-52 model) and where we have installed two 400 kW diesel generators.

The aim of the system is the simultaneous power generation between diesel generators and wind turbine, delivering energy to a load. This load should be a passive load of 800 kW, but for testing purposes as stand–alone system, a controlled load is needed. We have tried to use the resources of the wind farm and to diminish the changes in the equipment already installed. In fact, the power converter used for the controlled load is the same one that has been used in the wind turbine.

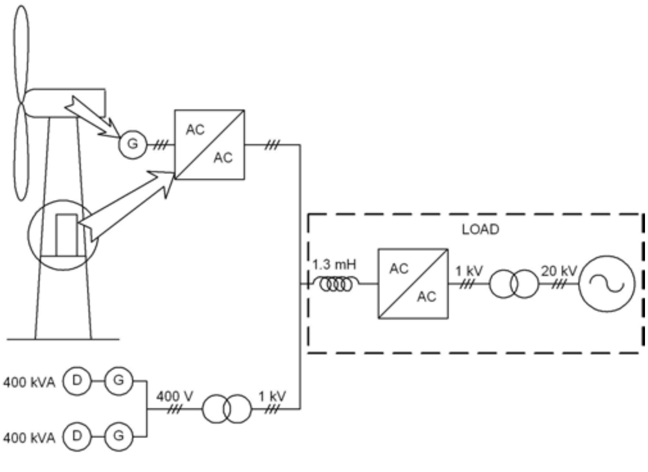

Fig. 3. Diagram of the wind-diesel test-bench.

A diagram of the test-bench is shown in Fig. 3. In this figure, different parts of the test–bench can be seen. The first part consists in the AE-52 wind turbine, where a synchronous generator it is used. The AC–AC converter used is that installed in the wind mill. The nominal output voltage of this converter is 1 kV. Secondly, it is possible to observe the two diesel engines linked at 400 V and the transformer that is used to connect them to 1 kV. Finally we have the load, that is compound of a three-phase inductor for smoothing, an AC-AC converter and 1 MW transformer to raise the voltage to the 20 kV for connecting to the public grid. In this way the power generated by the diesel engines and the wind turbine is injected into the public grid, not needing passive elements for the power dissipation.

The 1:20 kV transformer is located in the base of the wind mill and is the one used for the injection of the power generated by the wind turbine in grid-connected applications.

In Fig. 4 it is shown the diagram of the AC-AC converter. It is based on an uncontrolled rectifier, a chopper and finally an inverter DC-AC in order to inject the power to a grid. IGCT's technology has been used in the power circuit.

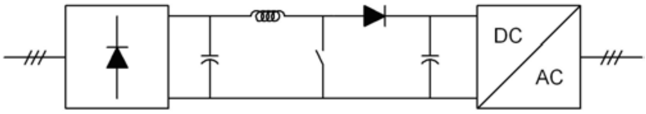

Fig. 4. Diagram of the AC-AC electronic converter.

It should be noted that this kind of load produces high currents harmonics. In addition, since our system is a stand-alone one, the grid is weak and with the use of this type of load we will have also voltage harmonics. Although this should represent a disadvantage, it will allow us to make a good test of the developed system and to confirm the stabilization benefits of the proposed control strategy.

III. Wind-Diesel Operation

The basic operation of the wind–diesel system is described as follow. On one hand, when the power coming from the wind is lower than the demanded power, the diesel generator increases its production in order to equal the demanded power. On the other hand, for high wind energy, the wind turbine increases its production meanwhile the diesel generator lower the delivered power. The diesel engines are not stopped at any time in order to maintain the voltage of the system. This is needed because the wind turbine is working like a current source, i.e., it injects power to the stand alone grid.

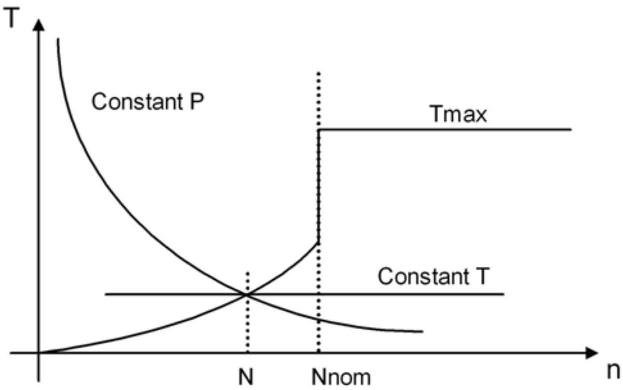

Fig. 5. Torque-Speed operation curve, and operation of the control at constant power and constant torque.

For a certain load level the power has to distribute between the wind turbine and the diesel generators. In order to minimize fuel consumption and reduce pollution, the wind turbine must inject the maximum power from the wind, except by a small amount of power, that is reserved for the diesel

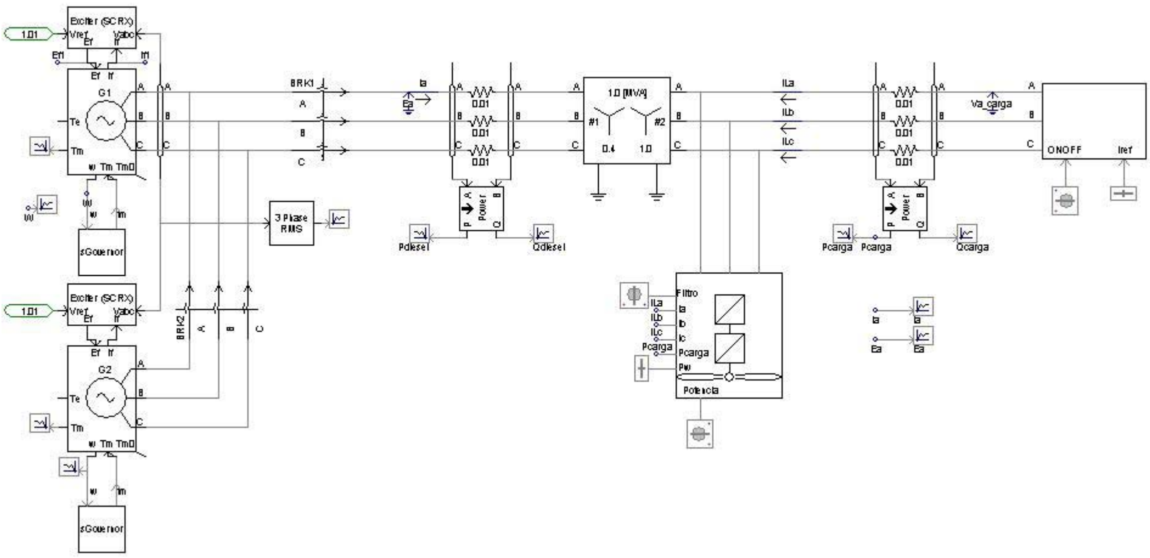

Fig. 6 Schematic of the simulator used in this project (PSCAD).

generators to maintain voltage stability. In this way, the wind turbine must follow a power reference. Two strategies has been developed in order to follow this power reference (Fig. 5).

The first strategy consists on making the wind turbine to work at constant power. The advantage of this control is its simplicity. For low power reference, the torque-speed curve is saturated by the constant power curve. For high power reference the wind turbine shows the same behavior as in grid–connected applications.

The second strategy consists on working at constant torque. The advantage of this control is that the wind turbine holds less efforts in the blades and the tower of the mill.

The control implemented in the wind turbine is based on the constant torque strategy.

IV. Simulation Results

In this project a full set of parameterized simulations have been made. The parameters used were load demand and wind speed. The main objective of these simulations is to know which are the worst conditions for the diesel generators. In particular, we are interested on the total harmonic distortion (THD) for voltage and current, and the power factor (PF), that is produced in the synchronous generators of the diesel engines at different load levels.

In Fig. 6 it is shown the schematic used for these sets of simulation. All simulations have been made with PSCAD [12].

In tables I, II and III simulation results of THD of current and voltage and PF have been represented for the worst case.

You can notice that the worst condition for the voltage [13] is produced when the load is close to its nominal value (700 kW) and there is a low wind speed (70 kW from wind turbine). The worst condition for the current is produced when the load and the wind speed are both low (100 kW). Nevertheless, the worst condition for the power factor is produced when the load and the wind turbine are close to their nominal value (700 kW).

Table I
Worst case for voltage THD in the diesel generators

Measure	Value	Unit
P_{Load}	700.0	kW
P_{Wind}	70.0	kW
P_{Diesel}	624.4	kW
Q_{Diesel}	574.0	kVAr
S_{Diesel}	848.1	kVA
cos φ	0.74	-
$THD_{VDiesel}$	18.5	%
$THD_{IDiesel}$	9.0	%

Table II
Worst case for current THD in the diesel generators

Measure	Value	Unit
P_{Load}	100.0	kW
P_{Wind}	100.0	kW
P_{Diesel}	80.0	kW
Q_{Diesel}	18.6	kVAr
S_{Diesel}	82.1	kVA
cos φ	0.97	-
$THD_{VDiesel}$	17.0	%
$THD_{IDiesel}$	84.6	%

Table III
Worst case for PF in the diesel generators

Measure	Value	Unit
P_{Load}	700.0	kW
P_{Wind}	700.0	kW
P_{Diesel}	80.0	kW
Q_{Diesel}	374.5	kVAr
S_{Diesel}	382.9	kVA

cos φ	0.21	-
$THD_{VDiesel}$	15.4	%
$THD_{IDiesel}$	21.8	%

In the next figures it has been represented simulation results for three levels of wind: 7m/s, 11 m/s (nominal wind speed for the AE-52 wind turbine) and 21 m/s. It can be observed four figures for each wind speed.

In the first one, it is represented the active and reactive power for the load and diesel generators. The difference between them is obviously, in absence of losses, the active and reactive power of the wind turbine, respectively.

In the second figure can be observed the current and voltage THD's for the load and diesel generators.

In the third figure the voltage evolution of the point of common coupling (PCC) is shown.

And finally, in the fourth figure, the frequency evolution appears as a function of the real time.

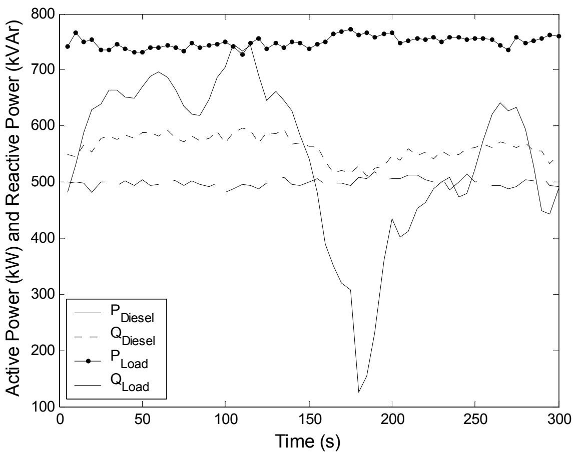

Fig. 7. Active and reactive power for the diesel and the load. Mean wind speed7 m/s.

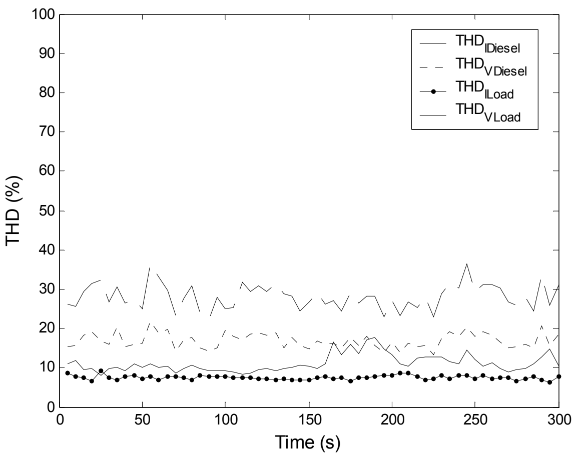

Fig. 8. THD for the current and voltage for the diesel and the load. Mean wind speed 7 m/s.

The case of low wind speed (7m/s) is presented in Fig. 7, where the diesel generator active power is not constant. When there is enough wind speed, the power injected by the wind turbine is enough to feed the load, and hence, decrease the active power of the diesel generators. However, the reactive power is maintained because the wind turbine doesn't inject reactive power.

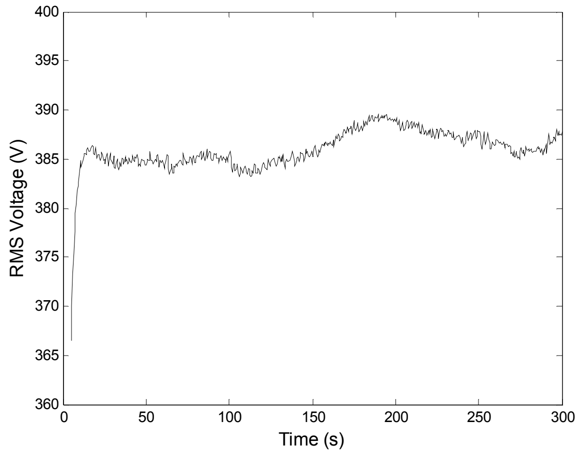

Fig. 9. Voltage in the point of common coupling. Mean wind speed 7 m/s.

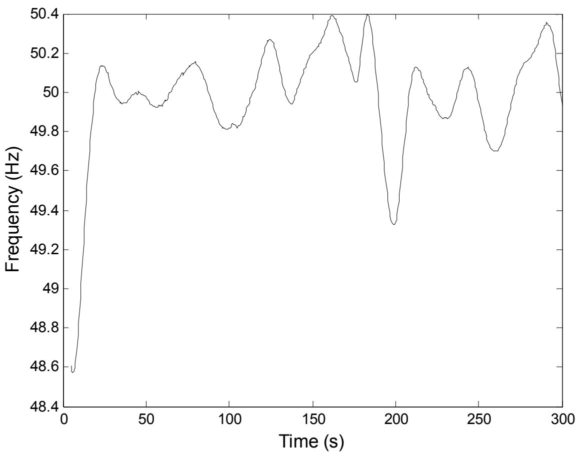

Fig. 10. Frequency in the stand alone system. Mean wind speed 7 m/s.

The load current THD is about 30% as shown in Fig. 8. This is due to the kind of the load, implemented with a non–controlled rectifier.

In Fig. 9 and Fig. 10, it can be observed that the voltage and the frequency are modified due to the wind variations. The fluctuations are 1.3% for the voltage and 2.0% for the frequency.

For the case of nominal wind speed (11 m/s) in Fig. 11, the active power of the diesel generators is constant, except when the wind falls bellow nominal.

In Fig. 13 and Fig. 14, it can be observed that the voltage is less affected than the frequency with the wind variations. The fluctuations in the frequency are the same than the case of 7m/s (2.0%).

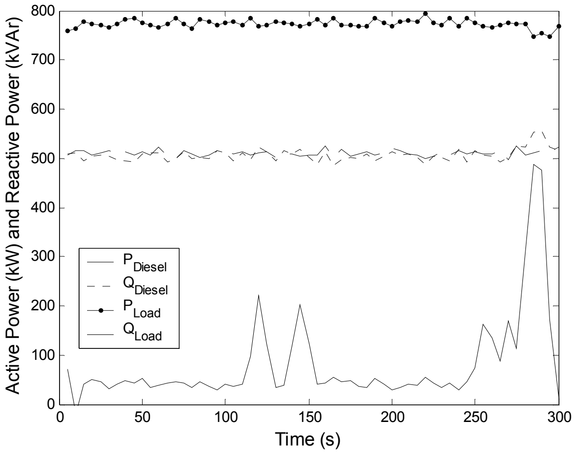

Fig. 11. Active and reactive power for the diesel and the load.
Mean wind speed 11 m/s.

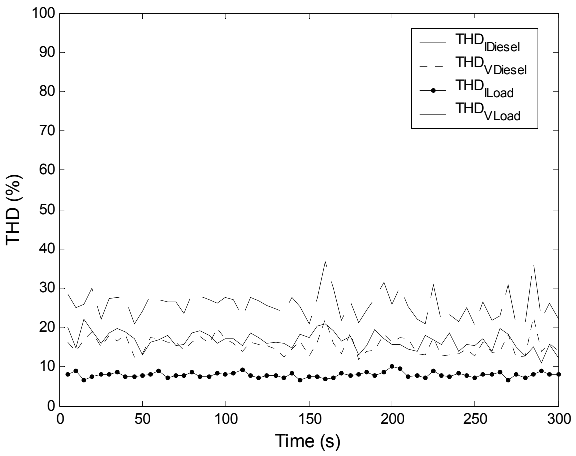

Fig. 12. THD for the current and voltage for the diesel and the load.
Mean wind speed 11 m/s.

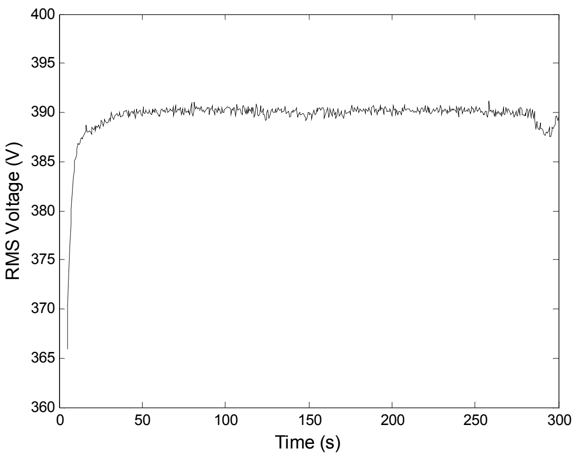

Fig. 13. Voltage in the point of common coupling.
Mean wind speed 11 m/s.

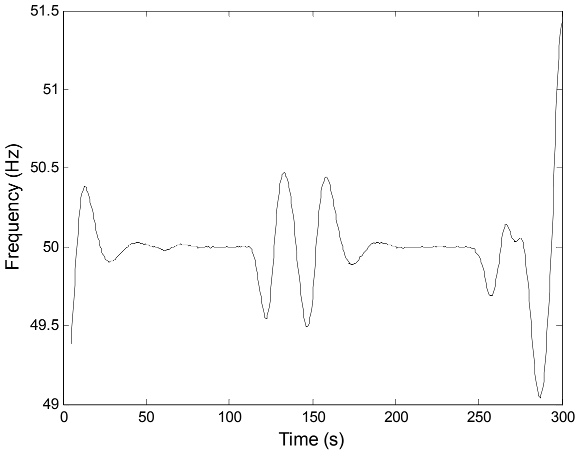

Fig. 14. Frequency in the stand alone system.
Mean wind speed 11 m/s.

In Fig. 15 it can be observed that in the case of above nominal wind speed (21 m/s) the active power of the diesel generators is very constant. This is due to the pitch regulation on the wind turbine.

In Fig. 17 and Fig. 18, it can be observed that the voltage and the frequency have very small variations (except in the initial transient).

In Fig. 8, Fig. 12 and Fig. 16, we can see the evolution of the current THD in the diesel generators with the wind speed (the voltage THD in the diesel engines, and the voltage and current THD's in the load are practically constant). When the wind speed is high, the current THD in the diesel engines is also high. This is due to the low power generated in the diesel gen-sets.

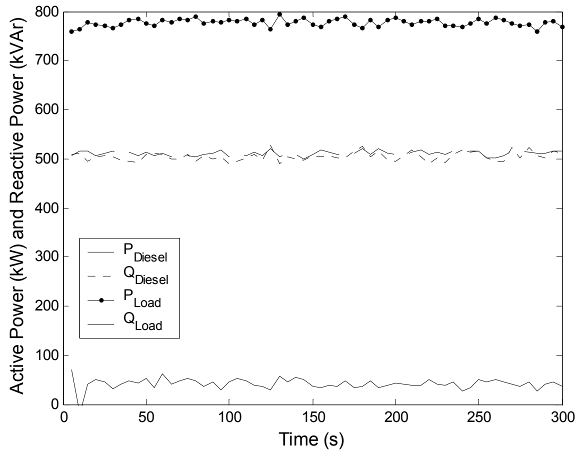

Fig. 15. Active and reactive power for the diesel and the load.
Mean wind speed 21 m/s.

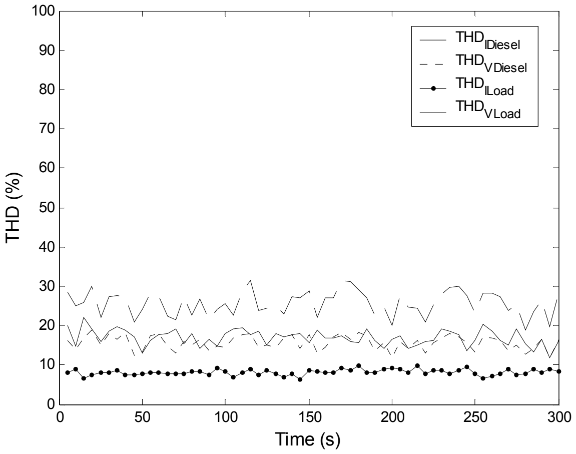

Fig. 16. THD for the current and voltage for the diesel and the load. Mean wind speed 21 m/s.

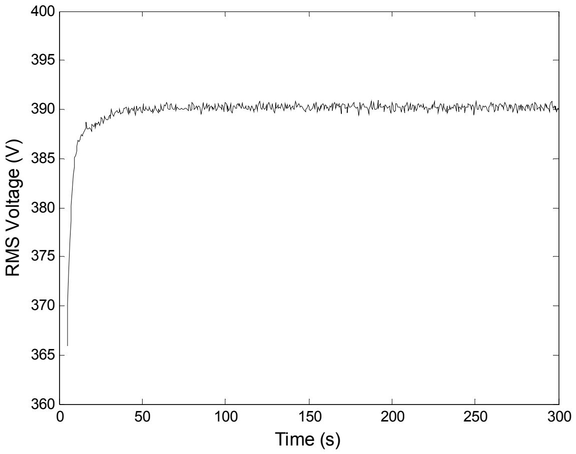

Fig. 17. Voltage in the point of common coupling. Mean wind speed 21 m/s.

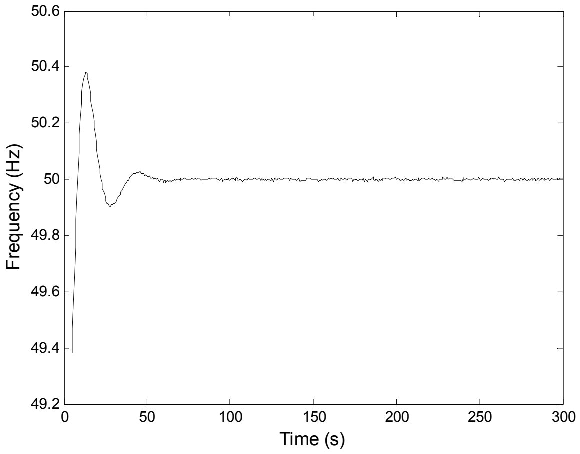

Fig. 18. Frequency in the stand alone system. Mean wind speed 21 m/s.

V. CONCLUSION

A test–bench have been presented for a 800 kW hybrid renewable energy system. It consists on a sets of diesel generators delivering energy to a load along with a 800 kW MADE AE-52 variable–speed, variable–pitch wind turbine. Several simulations results confirm the validity of the complete system, in order to stabilize the frequency and amplitude of the stand-alone system voltage, and to improve the power quality.

In addition, two control strategies have been presented in order to control the power delivery by the wind turbine into the isolated system.

Finally, the system has been installed at the Monteahumada wind farm (Tarifa), and it is prepared to obtain experimental results.

REFERENCES

[1] N. Moreno Alfonso, J.M. Carrasco Solís, E. Galván Díaz, J.A. Sánchez Segura, L. García Franquelo, S. Hurtado, G. Gostales, A. de Lara, “A new power stabilization control system based on making use of mechannichal inertia of a variable-speed wind-turbine for stand-alone wind-diesel applications". in proceedings of the 2002 IEEE International Conference on Industrial Electronics, Control and Instrumentation,vol. 1

[2] S. A. Papathanassiou, M. P. Papadopoulos, “Dynamic characteristics of autonomous wind–diesel systems”, Renewable Energy, Vol. 23, Issue 2, June 2001, pp. 293-311

[3] A. J. Bowen, M. Cowie and N. Zakay , “The performance of a remote wind–diesel power system”, *Renewable Energy*, Vol. 22, Issue 4, April 2001, pp. 429-445

[4] D. Das, S. K. Aditya and D. P. Kothari , “Dynamics of diesel and wind turbine generators on an isolated power system”, *International Journal of Electrical Power & Energy Systems*, Vol. 21, Issue 3, March 1999, pp. 183-189

[5] Hongwei Zhao, Xuanfu Li and Yuzhao Feng , “Optimum operation of large scale wind-diesel generation systems”, *Renewable Energy*, Vol. 16, Issues 1-4, 4 January 1999, pp. 851-854

[6] M. -U. -D. Mufti, “Simultaneous frequency and voltage control of wind-diesel power systems using energy storage”, *Fuel and Energy Abstracts*, Vol. 39, Issue 3, May 1998, pp. 202

[7] I.J. Iglesias, L. García-Tabarés and A. Agudo, "Design and Simulation of a Stand-alone Wind-Diesel Generator with a Flywheel Energy Storage System to Supply the Required Active and Reactive Power," in proceedings of the 2000 IEEE Power Electronics Specialists conference, vol. 3, pp. 1381-1386.

[8] I.J. Milanovi and N. Soultanis, "The influence of controlled and fixed load composition on operation of autonomous winddiesel system," in proceedings of the 2001 IEEE Power Tech., vol. 4.

[9] M.A.M. Prats, J.M. Carrasco, E. Galván. J.A.Sánchez, L.G.Franquelo and C.Batista, “Improving transition between power optimization and power limitation of variable-speed, variable-pitch wind turbines using Fuzzy control techniques,” in proceedings of 2000 IEEE International Conference on Industrial Electronics.

[10] M.M.Prats, J.M.Carrasco, E.Galván, J.A. Sánchez, L.G.Franquelo and C.Batista, “A New Fuzzy Logic Controller to Improve the Captured Wind Energy in a Real 800kW Variable-Speed Variable-Pitch Wind turbine,” in proceedings of 2002 IEEE Power Electronics Specialists Conference.

[11] N. Moreno, J.M. Carrasco, E. Galván, M. Perales, L.G. Franquelo, “DSP based emulator for Wind Power Generation Systems," in proceedings of the 2001 European Conference on Power Electronics and Applications.

[12] P.C. Krause, Analysis of Electric Machinery, McGraw-Hill, 1986, sec. 12.5.

[13] Spanish norma UNE-EN 50160, Características de la tension suministrada por las redes generales de distribución, AENOR, october 1996. Official spanish version from European Standard EN 50160, Voltage characteristics of electricity supplied by public distribution systems,”CENELEC European Committee for Electrotechnical Standarisation, November 1994.