INVESTIGATION OF A HYBRID ENERGY SYSTEM INCLUDING WIND GENERATOR

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Abstract: An energy weak grid consisting of a wind energy conversion system (WECS) which includes an asynchronous generator and a conventional plant consisting of diesel motor - synchronous generator unit, is analyzed. This system has been simulated via a developed general dynamic mathematical model which analytically describes the electric subsystems. Some interesting simulation results are presented in this paper. Specific attention is paid to the investigation of the dynamic analysis of the whole system at the connection and the disconnection of different nominal power WECS to the conventional plant for different wind velocity.

KEY WORDS: Energy weak grid, WECS, Simulation, Dynamic Behavior, Hybrid System.

1. Introduction

Wind is a significant and valuable renewable energy source and a remarkable progress has been made over the past decade. WECS is already one of the most cost – competitive renewable energy technologies.
Today, the cost is about 3 to 4 cents per kWh in USA, but in 1986 it was about 11-17 cents per kWh, respectively. The total cost of wind energy conversion system is brought to 900 – 1000 EUR per kW of installed capacity. The rapid decrease of the cost and the ecological and social benefits lead the wind power to be one of the world' s fastest growing energy sources. For example, in the end of 1996 around 3,4 GW of WECS capacity had been installed in Europe [9]. Ten years later around 8 GW will be installed and about 20 TWh of electricity per year should be provided, respectively. This would being a saving of nearly 17 10^6 tones of carbon dioxide per year. Energy storage can be a cost – effective component of hybrid remote power systems.

For this reason, the under investigation weak energy system that is modeled in this paper is a Wind – Diesel Hybrid System without energy storage. These systems are installed in small or medium size islands with good wind conditions.

In view of the weak grid characteristics, the use of this kind of systems requires appropriate control systems for the solution of instability and power quality problems. To obtain a large wind penetration, via the optimal exploitation of the wind potential, without problems for the electrical subsystems of the weak energy system and for the consumers, two control systems for the Diesel - S.G. unit are necessary.

By acting on the control the conventional unit operates in such a way that the fuel consumption and the excitation voltage get new values in relative to the electrical power that the WECS provides.

Analytically, this system consists of a unit of Diesel–Synchronous Generator and a unit of a wind motor and an asynchronous generator. There is also a short line, a transformer, an ohmic-inductive load and three control systems, one for active power – frequency control, one for control of the excitation voltage – stator voltage of the synchronous generator, and one for control of the angular velocity of the wind energy conversion system (WECS).

2. Description of the system under investigation

General hybrid systems are the most efficient for supporting the energy production and distribution system. It is known that the control systems in energy production and distribution are necessary for the stable and optimal operation of the whole energy system. The variations of the electrical power produced from the synchronous generator significantly depend on the wind - asynchronous generator operation. This is the reason why the hybrid systems are characterized as intelligent power systems (I.P.S.). In order to encounter the variations, automatic control systems are used for the synchronous - diesel unit and the wind motor - asynchronous generator unit.
Fig. 1 shows the basic structure of a hybrid energy conversion system with the block diagrams of the control systems. For the analysis of the whole system analytical equations for the description of the weak electrical grid using Park transformation for the generators and the basic aerodynamic equations for the wind motor are used. Through an optimization process, the appropriate values of the parameters for the control systems are obtained. The control is necessary for the production of electrical energy under the state of approximately stable frequency and voltage, according to the electrical grid rules.

A simulation based on the mathematical model, [5] and [6], was developed and used for the investigation of any dynamic condition. This simulation program has a flexibility and can be applied for any weak power system with proper extention of the WECS and offers the possibility to study any transient and steady state operation.

For the purpose of the present investigation, WECS with the nominal power are 200 kW, 1 MW and 2 MW (7%, 33% and 67% of the synchronous machines nominal power, if it is 3 MW respectively), are used.

For the investigation of the controllable dynamic behavior a simulation process via a general dynamic mathematical model appropriate for the study of any operation state is used [5, 6, 7].

This mathematical model comprised of twenty three differential equations is non linear and can be written in hypermatrices form as follows:

$$(C) * d(AGN)/dt = (A) * (AGN) + (B) * (GN) \quad (1)$$

where the matrices (C), (A), (B) are consisting of constant and variable elements, (AGN) is the matrix of the system variables and (GN) is the matrix of the voltages.

With this overall simulation model any transient condition can be investigated. This is important since it is well known that a qualitative and quantitative analysis of transient behavior is necessary for the power system design.

3. Simulation results

It is obvious that through the developed simulation code we have the possibility to investigate extensively the dynamic behavior of the weak energy grid's variables, to obtain useful information about the dumping current of the synchronous generator, the line current, the stator current of the generators, the terminal voltage of the S.G. and the variables of the control loops.
The current system' s parameters of the S.G. are:
P_N: nominal power of S.G. (= 3000 kVA)
U_N: nominal voltage of S.G. (= 15,75 kV = U_{ref})
$\cos\varphi_N$: nominal power factor of S.G. (= 0,9)
n_{NSG}: nominal rotation speed of the S.G. (= 428,5 rpm)
p_S: pore pair number of pole of the S.G. (= 7)
ω_{1o}: synchronous angular velocity (= 314,16 rad/s)
U_{FN}: nominal excitation voltage (= 75V)
Analytically the parameters of the whole system are presented at [7, 9].
Especially for two cases of transient situations, connection and disconnection of the WECS, via the simulation results we can point out the following main results:

a) in the initial time after the WECS connection, the quantitative variable's deviation currently depends on the nominal power of WECS (and the parameters of the asynchronous generator and the wind motor), but not on the produced electrical power (and the wind velocity),

b) during the first few seconds after the connection of the WECS with the grid, a reduction of the angular velocity of the S.G take place - these are due to the fact that at the beginning of the connection the asynchronous machine works as a motor because of the lack of the necessary magnetizing current – and

c) The oscillations magnitudes of all the system's variables are smaller during the disconnection process compared to the connection process, but the time needed for the system to get to the new steady state is about the same.

VARIABLES	*200 KW WECS*	*1 MW WECS*	*2 MW WECS*	*POWER RATIO OF WECS (1:5:10)*
Deviation of the WECS rotating velocity $\Delta\omega_R$	2%	9,5%	11,7%	1 : 4,8 : 5,9
Deviation of the S.G.'s rotating velocity $\Delta\omega_1$	1,27%	6,3%	9,6%	1 : 5 : 7,6
Deviation of the excitation current ΔI_{SF}	2,5%	14,6%	20%	1 : 5,8 : 8
dumping current of the S.G. I_{SDQ}	120 A	380 A	480 A	1 : 3,2 : 4
Deviation of the S.G.'s stator voltage.	9,2%	60%	78%	1 : 6,5 : 8

Table 1: Deviation of the electromechanical variables following the WECS connection to the grid.

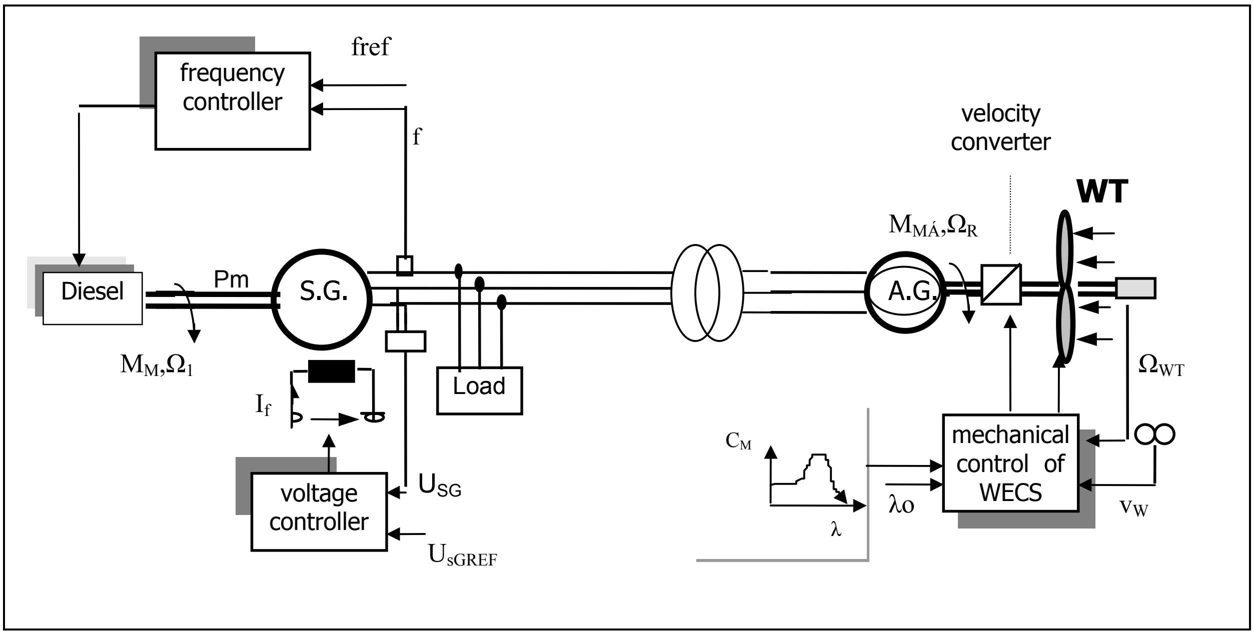


Fig. 1: Basic structure of a hybrid energy conversion system including WECS.

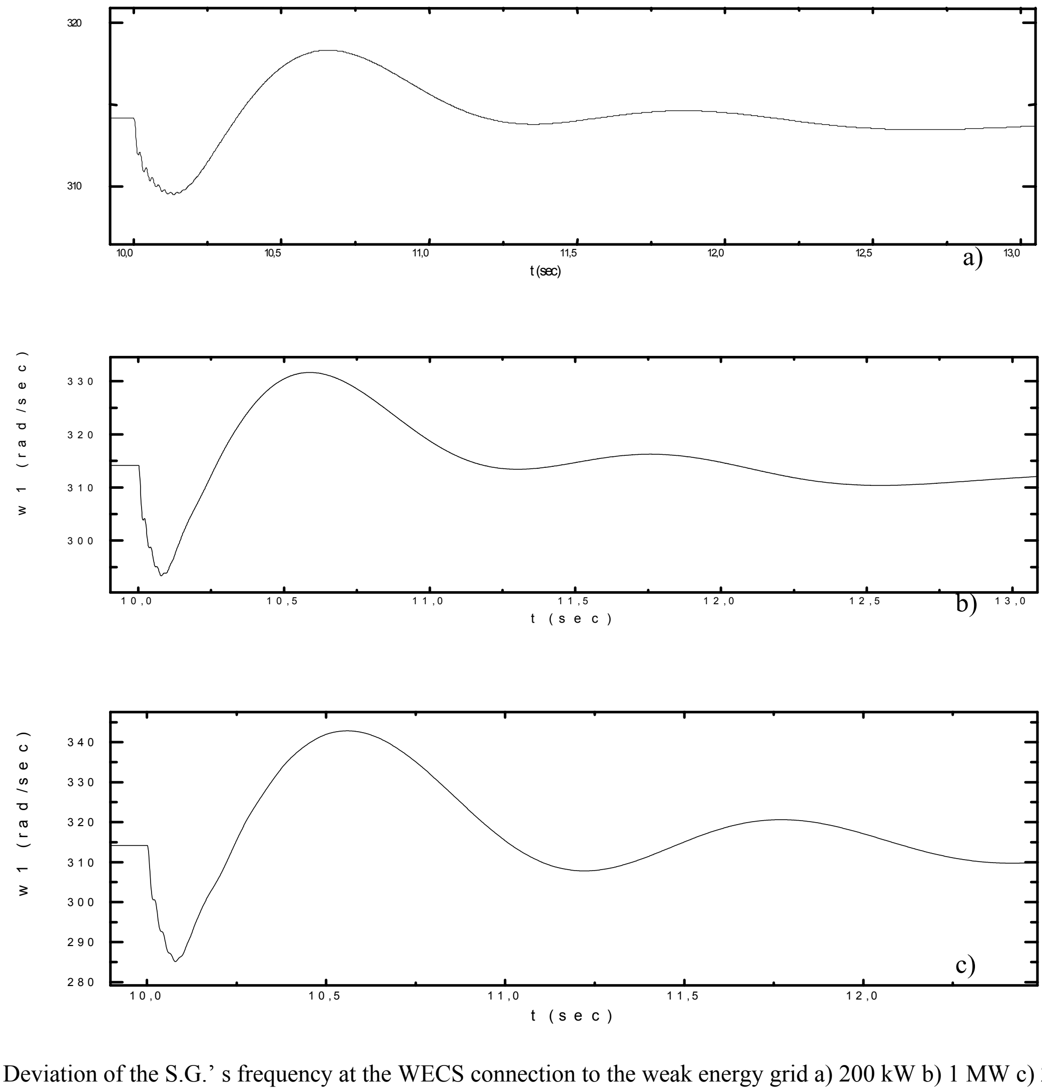


Fig. 2: Deviation of the S.G.' s frequency at the WECS connection to the weak energy grid a) 200 kW b) 1 MW c) 2 MW

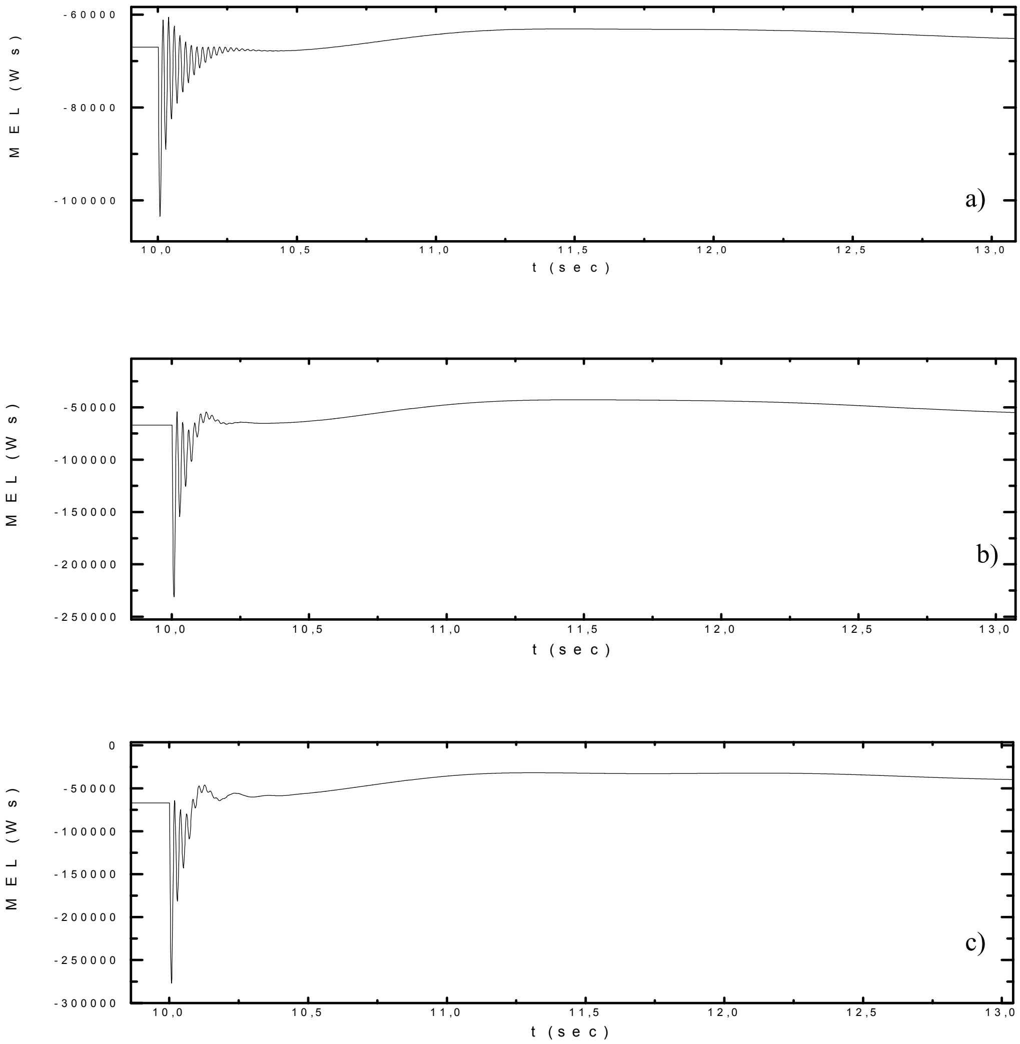


Fig. 3: Deviation of the S.G.'s electromagnetic torque at the WECS connection to the weak grid a) 200 kW b) 1 MW c) 2 MW

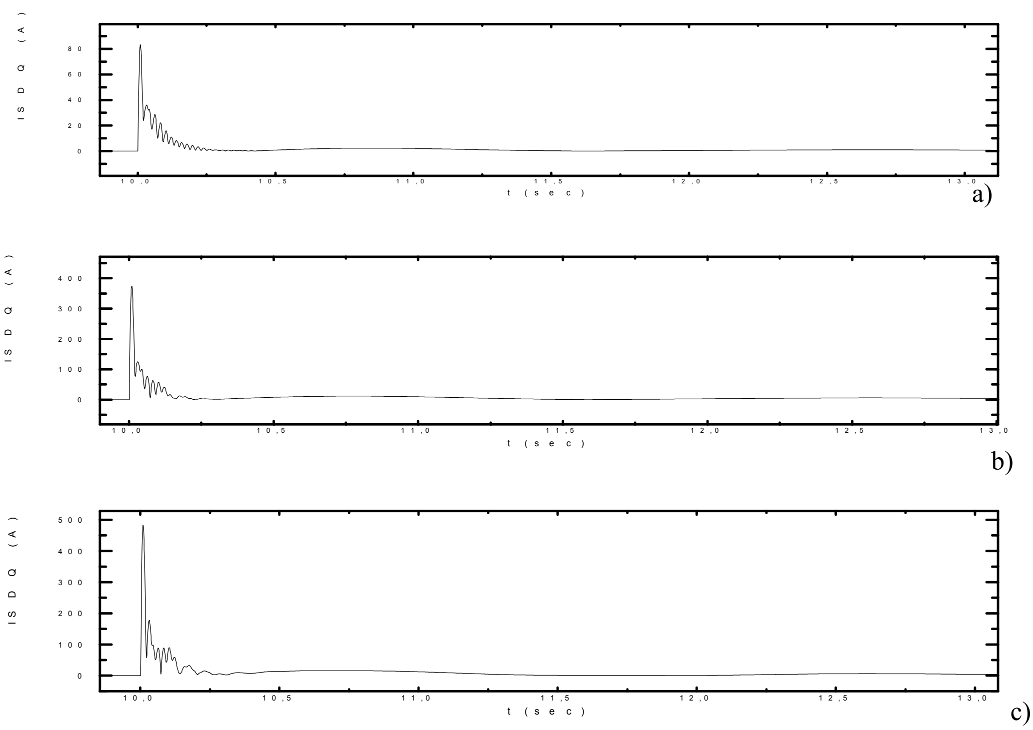
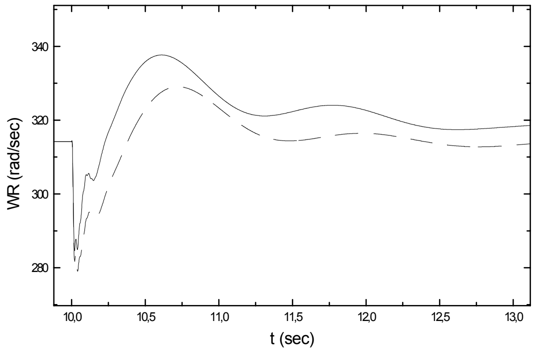
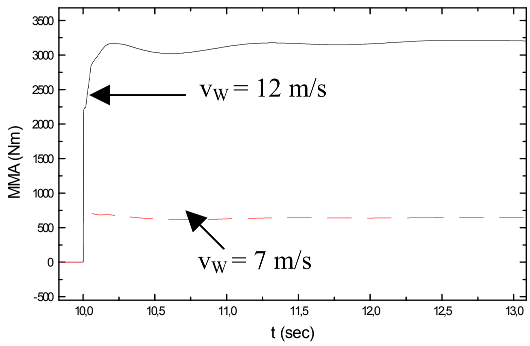


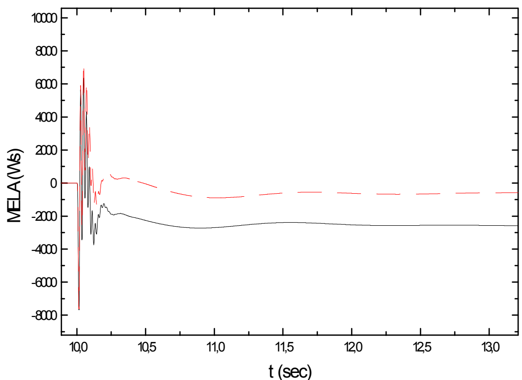
Fig. 4: Deviation of the S.G.'s dumping current at the WECS connection to the weak grid a) 200 kW b) 1 MW c) 2 MW

rotating velocity of WECS

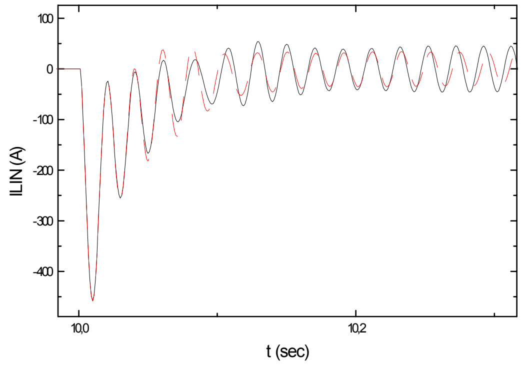




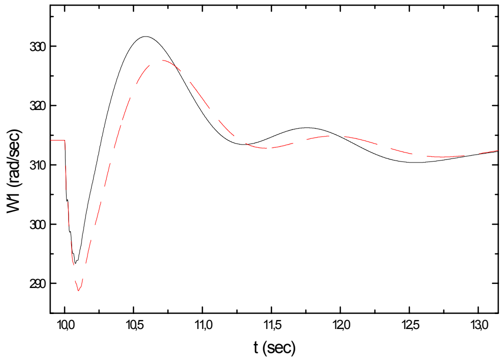
Mechanical torque of WECS



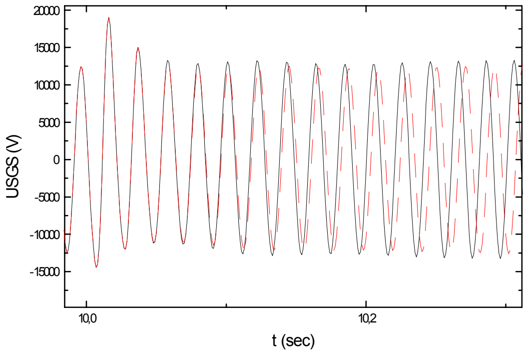
Electromagnetic torque of WECS.



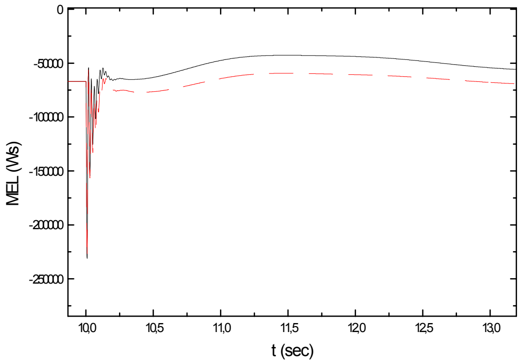
Phase line current



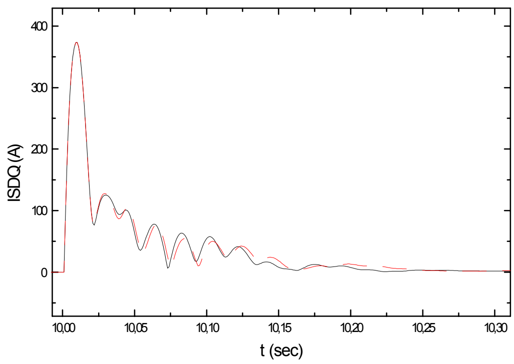
Rotating velocity of S.G.



Phase voltage of the S.G.'s stator.

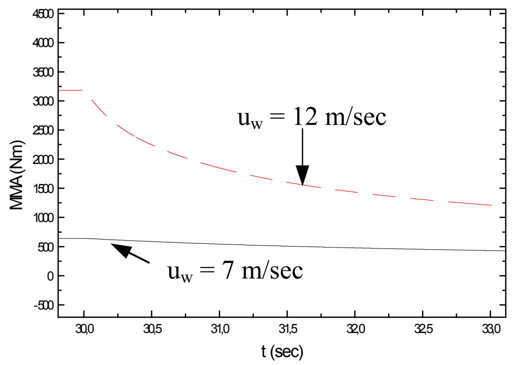


Electromagnetic torque of S.G..

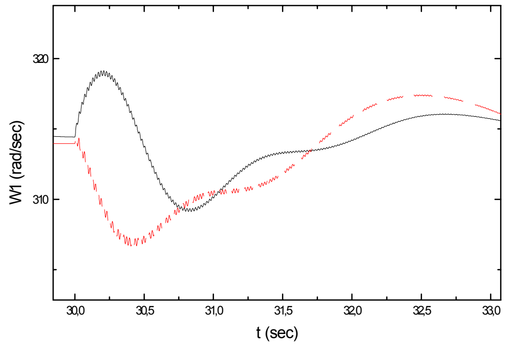


S.G.'s dumping current

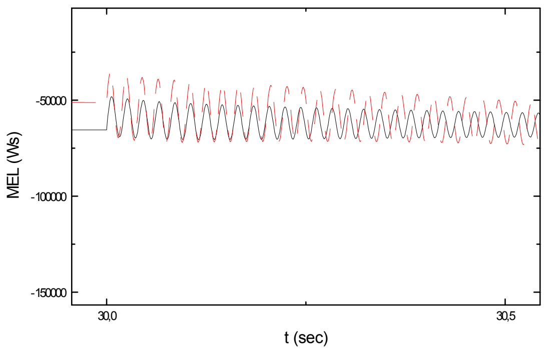
Fig. 5: Electromechanical variables following the 1 MW WECS connection with different wind velocities.



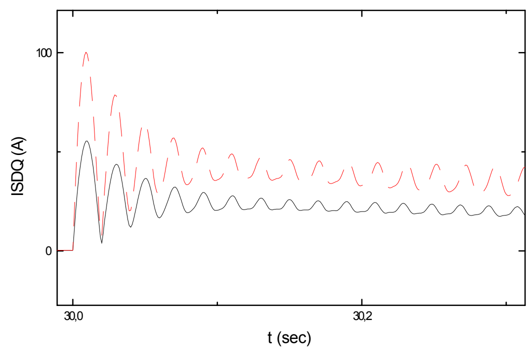
Mechanical torque of WECS



Rotating velocity of the S.G.



Electromagnetic torque of the S.G.



Dumping current of the S.G..

Fig. 6: Electromechanical variables following the 1 MW WECS disconnection with different wind velocities.

4.Conclusion

The dynamic behavior of a weak electric network, in which the production of electric energy is based on both fossil fuels and wind power for two characteristic cases, connection and disconnection of the WECS, was investigated in this study. A general dynamic mathematical model that can be used to study the behavior of such a system in detail was developed, using Park transformation and basic aerodynamic equations. In general, in the initial time after the WECS connection, the quantitative variable's deviation currently depends on the nominal power of WECS, but not on the produced electrical power, during the first few seconds after the connection of the WECS with the grid, a reduction of the angular velocity of the S.G take place and the oscillations magnitudes of all the system's variables are smaller during the disconnection process compared to the connection process, respectively.

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